İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

ENVIRONMENTAL ASSESSMENT OF SELECTED DIESEL AND BIODIESEL FUELS

M.Sc. Thesis by
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Programme : Chemical Engineering

JANUARY 2009

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Date of submission : **29 December 2008**
Date of defence examination: **22 January 2009**

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JANUARY 2009

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

SEÇİLEN DİZEL VE BİYODİZEL YAKITLARININ ÇEVRESEL DEĞERLENDİRMESİ

YÜKSEK LİSANS TEZİ

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Tezin Enstitüye Verildiği Tarih : 29 Aralık 2008
Tezin Savunulduğu Tarih : 22 Ocak 2009

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OCAK 2009

FOREWORD

This study aims to evaluate the environmental performance of biodiesel as an alternative fuel. In Turkey, biodiesel is the most attractive biofuel in recent years. Biodiesel production has gained an increasing attention, in parallel with increasing social consciousness of environmental problems. Many universities have carried out research studies on this topic and tens of biodiesel companies have been established. However, simple production of fuels from biological resources isn't equivalent to the production of environmentally friendly biofuels. Biofuels also have impacts on the environment at different stages of their life cycle. For this reason, a comprehensive study is required in order to compare and evaluate biodiesel as an alternative to the conventional petroleum based diesel fuel. The present study was carried out to fulfill that purpose.

Foremost, I would like to thank my advisor, Prof. Ekrem Ekinci, who shaped this research project with his immense expertise and research insight.

Many thanks go in particular to Assoc.Prof. Nilgün Cılız whose continuous assistance and valuable advices in science discussions throughout this project has made my research possible.

I would also like to express my gratitude to all of my managers and colleagues from EİE and TKB for their valuable suggestions and support of my thesis.

I am indebted to my lecturers from İstanbul Technical University for their continuous kindness and patience throughout my entire education term.

I am grateful to my family for their unlimited support and love. I especially would like to thank my lovely sister for her understanding and encouragement which is the most valuable thing for me.

December 2008 İlker ÖZATA

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ABBREVIATIONS

ALBIYOBIR	: Alternatif Enerji ve Biyodizel Üreticileri Birliği (Association of Alternative Energy and Biodiesel Producers)
B5	: 5% blend of biodiesel with diesel
B20	: 20% blend of biodiesel with diesel
CRFA	: Canadian Renewable Fuels Association
DfE	: Design for Environment
DfR	: Design for Recycling
EDIP	: Environmental Design of Industrial Products
EEA	: European Environment Agency
EIE	: Elektrik İşleri Etüt İdaresi (General Directorate of Electrical Power Resources Survey and Development Administration)
EI95	: Ecoindicator95
EMRA	: Energy Market Regulatory Authority of Turkey
EPA	: U.S.A. Environmental Protection Agency
Eq	: Equivalent
EU	: European Union
FAME	: Fatty Acid Methyl Esters
FPCCQ	: Fédération des Producteurs de Cultures Commerciales du Québec (Federation of the Commercial Culture Producers of Quebec)
GDP	: Gross Domestic Product
GHG	: Greenhouse Gas
GWP	: Global Warming Potential
IEA	: International Energy Agency
IKP	: Institute for Polymer Testing and Polymer Science, University of Stuttgart
IPP	: Integrated Product Policy
IPCC	: Intergovernmental Panel on Climate Change
ISO	: International Organization for Standardization
LCA	: Life Cycle Assessment
LCI	: Life Cycle Inventory
LCIA	: Life Cycle Impact Assessment
Pt	: Ecoindicator Point
NREL	: U.S.A. National Renewable Energy Laboratory
PE	: Person equivalent
pkm	: passenger kilometer
RME	: Rapeseed Methyl Ester
SETAC	: Society of Environmental Toxicology and Chemistry
SPM	: Suspended Particulate Matter
STM	: Société de Transport de Montréal (Corporation of the Transportation of Montreal)
tkm	: tonne kilometer
TPM	: Total Particulate Matter
TKB	: Türkiye Kalkınma Bankası (Development Bank of Turkey)

UV	**:** Ultraviolet
WCO	**:** Waste Cooking Oil

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LIST OF SYMBOLS

$EF(j)_i$	: Equivalency factor of environmental impact category j for an emission i.
ER(j)	: Normalization reference of impact category j for 1 year.
$ER_{EI95}(j)$	: Normalization reference of impact category j according to Ecoindicator95
EP(j)	: The potential contribution of impact category j.
$EP(j)_i$	: The potential contribution of impact category j for an emission i.
i	: Emission
j	: Impact Category
NEP(j)	: Normalized impact potential of j
Q_i	: Magnitude of emission i
T	: Year
WEP(j)	: Weighted impact potential of j
WF(j)	: Weighting factor of impact category j

ENVIRONMENTAL ASSESSMENT OF SELECTED DIESEL AND BIODIESEL FUELS

SUMMARY

Nowadays, energy security and sustainability are in the centre of globalization. Admittedly, increasing energy costs and social facing to environmental problems related with energy supply push the society to be more sensitive about environment-energy dilemma. Management of this process has emerged as the biggest challenge for the policy makers. In this context, biofuels are the focus point of the rising global trend.

Global warming and climate change are considered as the biggest threats to the world by most of the society. Biofuels having biogenic carbon content are an important alternative to sustain carbon cycle and to limit carbon dioxide emissions that cause global warming. However, global warming is not only environmental problem. Human activities have more than one impact on the environment. Interactions between environmental impacts and total cost of these impacts are required for the comprehensive evaluation. It requires deeper evaluation of wide range data from different disciplines. The integrated technology of today's world requires a comprehensive assessment method to evaluate these data in the context of systematic and sustainable approach. One of these methods, most widely used in the world, is Life Cycle Assessment (LCA). LCA is a tool that has been extensively used in the evaluation of environmental performance for many years and has been continuously developing. Policy makers support their policies with LCA results on energy, environment and costs.

Many LCA studies have been performed on the subject of biofuels. Due to their biological carbon content, biofuels emerge as an attractive alternative to conventional fuels in terms of limiting global warming. However, conventional fuels are widely used in the life cycle of biofuels and cause additional environmental impacts. Moreover, environmental impacts should not be limited only to global warming. Evaluation of other environmental impacts according to targeted problem is a basis of sustainability. Land-use and comparative performance are two other important criteria.

In the recent years, Turkey has expressed a big interest in biofuel applications. Admittedly, biodiesel production is a milestone of Turkey's biofuel journey. However, the LCA applications on possible biofuel alternatives in Turkey have not been developing parallel to the biofuel market. Biodiesels from two different feedstocks are studied within the scope of the thesis. Rapeseed oil and waste cooking oil (WCO) biodiesel-diesel blends (biodiesel blends) are compared with conventional petroleum based diesel (diesel) using LCA approach. In addition to global warming other environmental impacts such as eutrophication, acidification, photochemical oxidant formation, winter smog, heavy metals and carcinogenic substances are evaluated in the study. As a result, the total environmental performance of biodiesel blends in comparison with conventional diesel is aimed.

Although rapeseed biodiesel blends have a positive performance on the carbon dioxide emissions, they show worse environmental performance compared to the diesel when the other environmental impacts are included in the analysis. However, WCO biodiesel production is considered as a top-priority in recycling of waste cooking oils and is a starting phase of Turkey's biofuel journey.

SEÇİLEN DİZEL VE BİYODİZEL YAKITLARININ ÇEVRESEL DEĞERLENDİRMESİ

ÖZET

Günümüzde enerji güvenliği ve sürdürülebilirlik küreselleşmenin merkezinde bulunmaktadır. Şüphesiz ki, artan enerji maliyetleri ve enerji arzıyla ile ilişkili çevre problemleriyle sosyal yüzleşme, toplumu enerji-çevre ikilemi konusunda daha duyarlı olmaya zorlamıştır. Bu sürecin yönetilmesi karar vericiler için en büyük mücadele olarak ortaya çıkmıştır. Bu bağlamda biyoyakıtlar yükselen yeni küresel eğilimin odak noktasıdır.

Küresel ısınma ve iklim değişikliği toplumun çoğunluğu tarafından dünya için en büyük tehlike olarak görülmektedir. Biyolojik karbon içeren biyoyakıtlar karbon döngüsünü sağlama ve küresel ısınmaya sebep olan karbon dioksit emisyonlarını sınırlamaları nedeniyle önemli bir alternatiftir. Bununla beraber küresel ısınma tek çevresel etki değildir. İnsan faaliyetleri çevre üzerinde birden fazla etkiye sahiptir. Çevresel etkiler arasında etkileşimler ve bu etkilerin toplam maliyeti kapsamlı bir değerlendirme gerektirmektedir. Bu faklı disiplinlerden geniş kapsamlı verilerin derinlemesine değerlendirilmesine ihtiyaç duymaktır. Günümüz Dünyası'nın entegre teknolojisinin bu verilerin sistematik ve sürdürülebilir bir yaklaşım konseptinde değerlendirilmesi için kapsamlı bir değerleme aracına ihtiyacı vardır. Bunlardan biri, bütün dünyada geniş çapta kullanılan, Yaşam Döngüsü Değerlendirmesidir. Yaşam Döngüsü Değerlendirmesi, çevresel performansın değerlendirilmesinde dünyada uzun yıllardır kullanılan ve sürekli gelişen bir araçtır. Karar vericiler kararlarını enerji, çevre ve maliyetler üzerine LCA çıktıları ile desteklemektedirler.

Biyoyakıt konusu üzerine pek çok LCA çalışması gerçekleştirilmiştir. Biyoyakıtlar sahip oldukları biyolojik karbon nedeniyle küresel ısınmanın sınırlandırılmasında geleneksel yakıta karşı çekici bir alternatif olarak ortaya çıkmıştır.. Bununla birlikte, geleneksel yakıtlar biyoyakıtların yaşam döngüsü içerisinde geniş ölçekte kullanılmaktadırlar ve çevresel etkilere sebep olmaktadırlar. Üstelik, çevresel etkiler sadece küresel ısınma ile sınırlandırılmamalıdır. Hedeflenen probleme göre diğer çevresel etkilerin de değerlendirilmesi sürdürülebilirliğin temelidir.Toprak kullanımı ve karşılaştırmalı performans diğer önemli iki kriterdir.

Son yıllarda, Türkiye biyoyakıt uygulamaları konusunda büyük bir ilgiye sahip olmuştur. Kuşkusuz ki, biyodizel uygulamaları Türkiye'nin biyoyakıt yolculuğunda bir kilometre taşıdır. Bununla beraber, Türkiye için alternatif olabilecek biyoyakıtlar üzerine yaşam döngüsü değerlendirmesi uygulamaları biyoyakıt pazarına parallel gelişmemiştir. Tezin kapsamında, iki farklı hammaddeden biyodizeller çalışılmıştır. Kolza yağı ve atık yemeklik yağ biyodizel-dizel karışımları (biyodizel karışımları), geleneksel petrol bazlı dizel (dizel) ile yaşam döngüsü değerlendirmesi kullanılarak karşılaştırılmıştır. Küresel ısınmaya ek olarak ötrofikasyon, asitleşme, fotokimyasal oksidant oluşumu, asidik sis, ağır metaller ve kanserojen maddeler gibi çevresel etkiler çalışmada değerlendirilmiştir. Sonuç olarak, biyodizel karışımlarının geleneksel dizel ile karşılaştırmalı toplam çevresel performansı hedeflenmiştir.

Kolza biyodizeli karışımları karbon dioksit emisyonlarında pozitif performansa sahip olsa da, analize diğer çevresel etkiler katıldığı zaman dizele göre daha kötü bir çevresel performans göstermişlerdir. Bununla beraber atık yemeklik yağlardan biyodizel üretimi, atık yemeklik yağların geri kazanılmasında ve Türkiye'nin biyoyakıt yolculuğunun ilk fazında birincil öncelik olarak belirlenmiştir.

1. INTRODUCTION

Providing secure and environmentally friendly energy sources is key to ensuring the sustainable development of a country. Transportation is one of the biggest energy consuming sectors in the world. As a developing country Turkey, faces with the increasing emissions and decreasing quality of life because of the negative impacts of development. Due to this fact, environmentally friendly sustainable transportation technologies require a special attention. However, it is important to consider all effects of alternative technologies during the evaluation process. Evaluation of total environmental benefits needed for the development of new environmental policies, require simulation of the alternative technologies. Biodiesel blends from two different feedstocks are compared with the conventional diesel in the study. Life Cycle Assessment (LCA) approach is used as a basis for evaluation of the alternatives [1-5].

1.1 Purpose of the Thesis

The aim of the environmental assessment in this report is to criticize the environmental burdens and environmental efficiency of biodiesel as an alternative biofuel technology available in Turkey. Renewability is the key concept in the evaluation of biofuel technologies. The availability of biofuels in the country is related to the environmental, social and economical status of that country. The ability of a country to produce and consume biofuels is also dependent on the availability of technologies [3,4,6,7].

Environmental loads are assessed in order to evaluate the environmental performance of rapeseed and waste cooking oil (WCO) biodiesels. Thesis covers environmental assessments of biodiesels and provides a comparison of environmental performances of using two alternative feedstocks. The feedstock availability is assessed in the country scope. The assessment is based on scientific studies and political scenarios.

LCA of biofuels are currently widely performed in governmental and private institutions worldwide. Denmark, USA, Germany are the technology leaders of the LCA applications. Wide ranges of databases related to LCA are available for these countries. Additionally, Australia, UK and Canada have performed comprehensive life cycle studies on the transport fuels [7-13].

1.2 Background

Increasing transport demand emerges as one of the most widespread needs of the modern society. Transport sector is one of the biggest markets in the world. Environmental impact of this sector is enormous if we evaluate sub and ancillary sectors of transportation. In environmental perspective, biofuels are a good alternative for substitution of fossil fuels and providing security of energy supply. Increasing transport demand will be more problematic for the modern societies in the future. Transportation has been based on the fossil fuels since the industrial revolution. However, satisfying the increasing energy demand is impossible on the long range. Petroleum is also an indispensable raw material for many sectors. It is clear that importance of petroleum will increase with decreasing energy supply in the long term perspective and the bill of oil import for countries dependent on foreign oil will be more serious than today [1-4, 14].

In recent years, liquid biofuels such as bioethanol and biodiesel have received serious attention in Turkey. Although this attention is mainly due to high petroleum prices, it creates a platform to discuss environmental friendly biofuel technologies. Dependency of oil import increases in Turkey as illustrated in Figure1.1. Many of biodiesel producing firms were set up in a short period of time as illustrated in Figure 1.2. However, because of the lack of technological qualifications, high vegetable oil prices and regulatory obligations many of them are closed today [5,15,16].

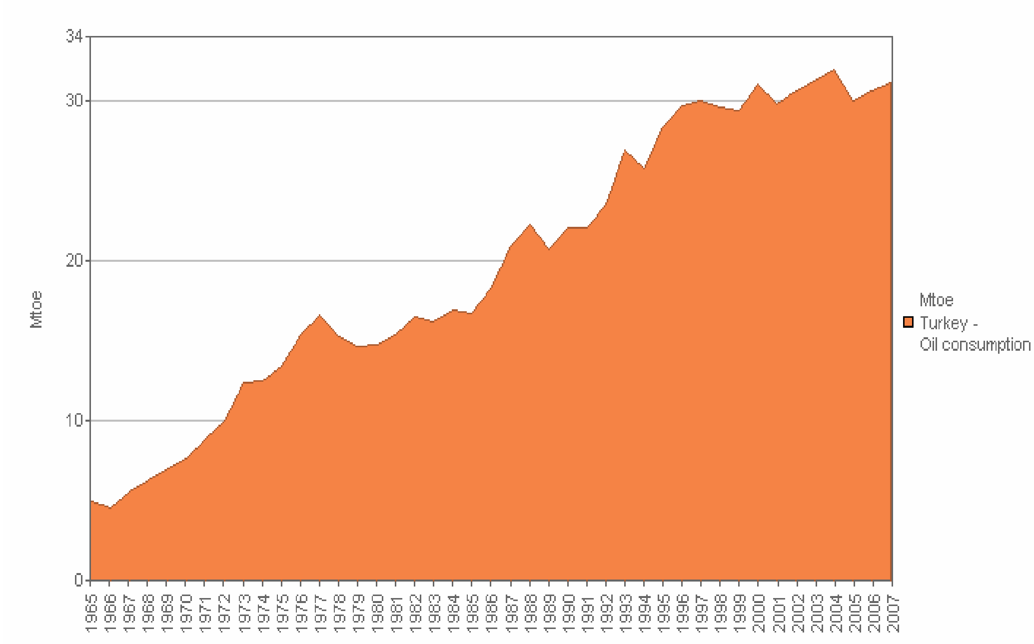


Figure 1.1 : Oil consumption of Turkey [5].

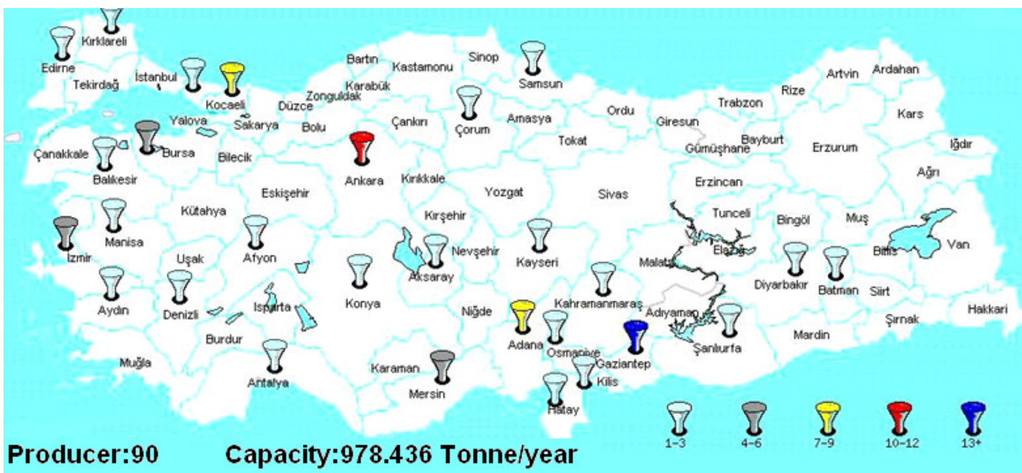


Figure 1.2 : Biodiesel producers and their capacities in 2005 [15].

However, with the recent developments in alternative transportation fuel industry, a new phase has started in Turkey. Many research studies have revealed more available and environmentally friendly biofuels for Turkey despite of bad experiences of the past. These developments create a possibility for gaining higher biofuel yields using available feedstocks while producing less emission than conventional fuels.

Currently, production of biofuels in Turkey focuses on the first generation biofuels. Second generation biofuel technologies are performed only on academical level. Additional problems arise from the land availability for biofuels. Turkey is a vegetable oil importer country and there is a chaotic situation in agriculture, which is related to social and economical conditions [17]. Due to this situation, the land availability is kept out of the thesis concept.

Rapeseed is the most available feedstock for biodiesel production in Turkey. Later works show that yield of rapeseed agriculture increases with increasing experience. On the other hand, collecting of WCO for recycling has gained a greater in the recent years. WCO became a more serious biodiesel feedstock after the regulation of biodiesel market. However, more improvements need to be carried out in the collecting of WCO. Recent qualities of WCO are usually insufficient for the production of biodiesel that meets the quality standards. Social consciousness and further regulatory obligations are needed to gain more WCO than today [16,18-20].

1.3 Hypothesis

LCA is one of the most comprehensive method for the evaluation the environmental assessments of products. Scenarios created with LCA serve the policy makers realistic and data based criterions [21,22]. LCA method used in this work is in agreement with the ISO 14040 requirements. GaBi4 software is used for modeling the LCA scenarios.

LCA of rapeseed biodiesel blends, WCO biodiesel blends with conventional diesel are evaluated. Two biodiesel blends; B5 (%5 volumetric biodiesel) and B20 (%20 volumetric biodiesel) are considered in the study. Biodiesel production creates a couple of by-product. Allocation procedure is used to share environmental burdens for co-products and by-products. Rapeseed straw in rapeseed biodiesel life cycle is neglected in the allocation. Rapeseed meals and glycerine are allocated on the basis of economical allocation.

Diesel bus is used as a combustion process of biofuels. Fuel efficiencies for biodiesel and diesel are considered different according to the real values of the scientific studies. The most productive process is considered for the biodiesel production. Energy needs of the processes are accepted to be supplied by grid electricity and steam from natural gas [10,11,13,23].

Although biodiesel is allowed to be blended in low levels with diesel in Turkey, higher biodiesel blends are chosen for the study [16]. It is based on the future targets of European Union (EU) and relations of Turkey with EU. Additionally, lower level biodiesel blends create economical pressure on the biodiesel producers because of voluntary use of biodiesel by fuel distributor firms.

Global warming is a serious environmental impact that affects the decision of policy makers of the countries [4]. However, it is not the only environmental impact. Acidification potentials, eutrophication potentials, photochemical oxidant formation, heavy metals, carcinogenic substances and winter smog potential are evaluated along with the global warming potential. These effects may become as important as global warming potential depending on the countries' special conditions. Moreover, evaluation of environmental impacts is a local process in some cases.

Ecoindicator95 factors are used to weight environmental impacts. It is shown that more integrated and effective production systems are needed to substitute diesel. It is determined that the rapeseed biodiesel also has high impacts on the environment. However, utilization of WCO is considered as a top priority because of the higher environmental performance.

2. LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is a process of evaluating the effects that a product has on the environment over the entire period of its life cycle [24]. The term "life cycle" refers to the major activities in the course of the product's life-span from its manufacture, use, and maintenance, to its final disposal, including the raw material acquisition required to manufacture the product [21]. Sometimes also called "life cycle analysis", "life cycle approach", "cradle to grave analysis" or "Ecobalance", it represents a rapidly emerging family of tools and techniques designed to help in environmental management and, longer term, in sustainable development [22]. It provides objective data that are not dependent on any ideology and it can be used to study the environmental impact of either a product or of the function, a product is designed to perform [24].

LCA is based on systems analysis, treating the product process chain as a sequence of sub-systems that exchange inputs and outputs. The results of an LCA quantify the potential environmental impacts of a product system over the life cycle, help to identify opportunities for improvement and indicate more sustainable options where a comparison is made. [25]

The International Organization for Standardization (ISO) has defined an LCA as: A technique for assessing the environmental aspects and potential impacts associated with a product by [8]:

- Compiling an inventory of relevant inputs and outputs of a product system.
- Evaluating the potential environmental impacts associated with those inputs and outputs.
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

In accordance with the present consensus within Society of Environmental Toxicology and Chemistry (SETAC) and in agreement with the current ISO14040 standard, the life cycle assessment consists of the following phases [26]:

- Goal and Scope Definition
- Inventory Analysis
- Impact Assessment
- Interpretation

2.1 LCA Methodology

The LCA process is a systematic, phased approach and consists of four components: goal and scope definition, inventory analysis, impact assessment, interpretation [21]. According to the ISO components of LCA are illustrated in Figure 2.1.

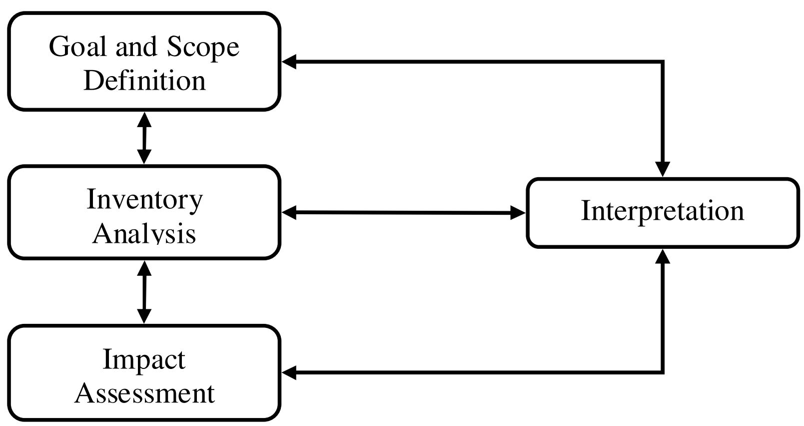


Figure 2.1 : Life cycle assessment framework.

The goal and scope definition phase clearly states the intended objectives of the LCA application, and define the system under study [27]. Life cycle inventory analysis (LCI) phase involves the compilation and quantification of inputs and outputs for a given product system throughout its life cycle [28]. The environmental significance of these substances is assessed in the life cycle impact assessment phase (LCIA). The interpretation is the final phase of the LCA, in which the results of LCI and LCIA are discussed in the light of the goals set in the beginning of the study [27].

As an unique method LCA encompasses all processes and environmental releases beginning with the extraction of raw materials and the production of energy used to create the product through the use and final disposition of the product. When deciding between two or more alternatives, LCA can help decision-makers compare all major environmental impacts caused by products, processes, or services [21].

2.1.1 Goal and scope definition

The “Goal and scope definition” describes the underlying questions, the target audience, the system boundaries and the definition of a reference flow for the comparison of different alternatives [29]. Goal definition defines the purpose of the study and decision process to which it shall provide input of environmental information [26]. Object of the assessment is defined in the scope definition. Different items are included in the scope definition [7].

- Functional Unit
- Reference product/systems
- Assessment criteria
- Scope definition of product system
- Geographical scope
- Temporal and technological scope
- System equivalence
- Boundary conditions

The base of the analysis is functional unit that provides a clear, full and definitive description of the product or service being investigated, enabling subsequent results to be interpreted correctly and compared with other results in a meaningful manner [25]. For this reason, it must be clearly defined in quantitative terms.

2.1.2 Inventory analysis

The second stage of an LCA is the life cycle inventory analysis. This involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system [29]. The objective of the inventory is to collect environmentally relevant information for the processes included in the model of the product system. Inventory data include all relevant inputs and outputs for the processes such as raw material consumption, electricity consumption, heat and steam consumption, emissions and transport work, etc [7].

General rules of thumb concerning the quality of data for inventory prescribe the use of [26]:

- The most recent data
- Quality-assured and declared data
- Specific data whenever relevant and possible for both specific and general LCAs
- General or estimated data when sufficient and when specific data are not available
- Quantitative data when possible

2.1.3 Life cycle impact assessment

Impact assessment is the component in which the results of the inventory analysis are interpreted in terms of the impacts they have on the environment. These environmental effects then have to be compared in order to reach an overall assessment of the products investigated [24].

The key concept in this component is that of stressors. A stressor is a set of conditions that may lead to an impact. For example, if a product or process is emitting greenhouse gases, the increase of greenhouse gases in the atmosphere may contribute to global warming. Processes that result in the discharge of excess nutrients into bodies of water may lead to eutrophication. An LCIA provides a systematic procedure for classifying, characterizing, normalizing and weighting these types of environmental effects [21].

The interpretation performed in the assessment phase of LCA normally proceeds through four steps.

- Classification
- Characterization
- Normalization
- Weighting

2.1.3.1 Classification

In the classification, all environmental "stressors" (resources used as inputs and emissions vented to the environment) are classified according to the kind of environmental problem to which they contribute. The categories of some environmental problems are given below [24]:

- Resource depletion
- Energy depletion
- Global warming
- Acidification
- Heavy metals
- Nitrification
- Ozone depletion
- Eutrophication
- Photochemical oxidation
- Winter Smog

Cause-impact network for environmental emissions are shown in Figure 2.2.

Acidification occurs when emissions of sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) react in the atmosphere with water, oxygen, and oxidants to form various acidic compounds. It is commonly known as acid rain. Other agents causing acidification are ammonia, HC1, HF [30].

Eutrophication is the reduction in water quality caused by excess nutrient loading. Eutrophication damages the aesthetic and recreational water qualities, as well as altering species composition. Water can become opaque with unpleasant taste and odors [30].

Global warming, or the "greenhouse effect," is defined as the changes in the Earth's climate caused by a changed heat balance in the Earth's atmosphere. CO_2 is the most important greenhouse gas. Two of the other greenhouse gases are N_2O, CH_4 [30].

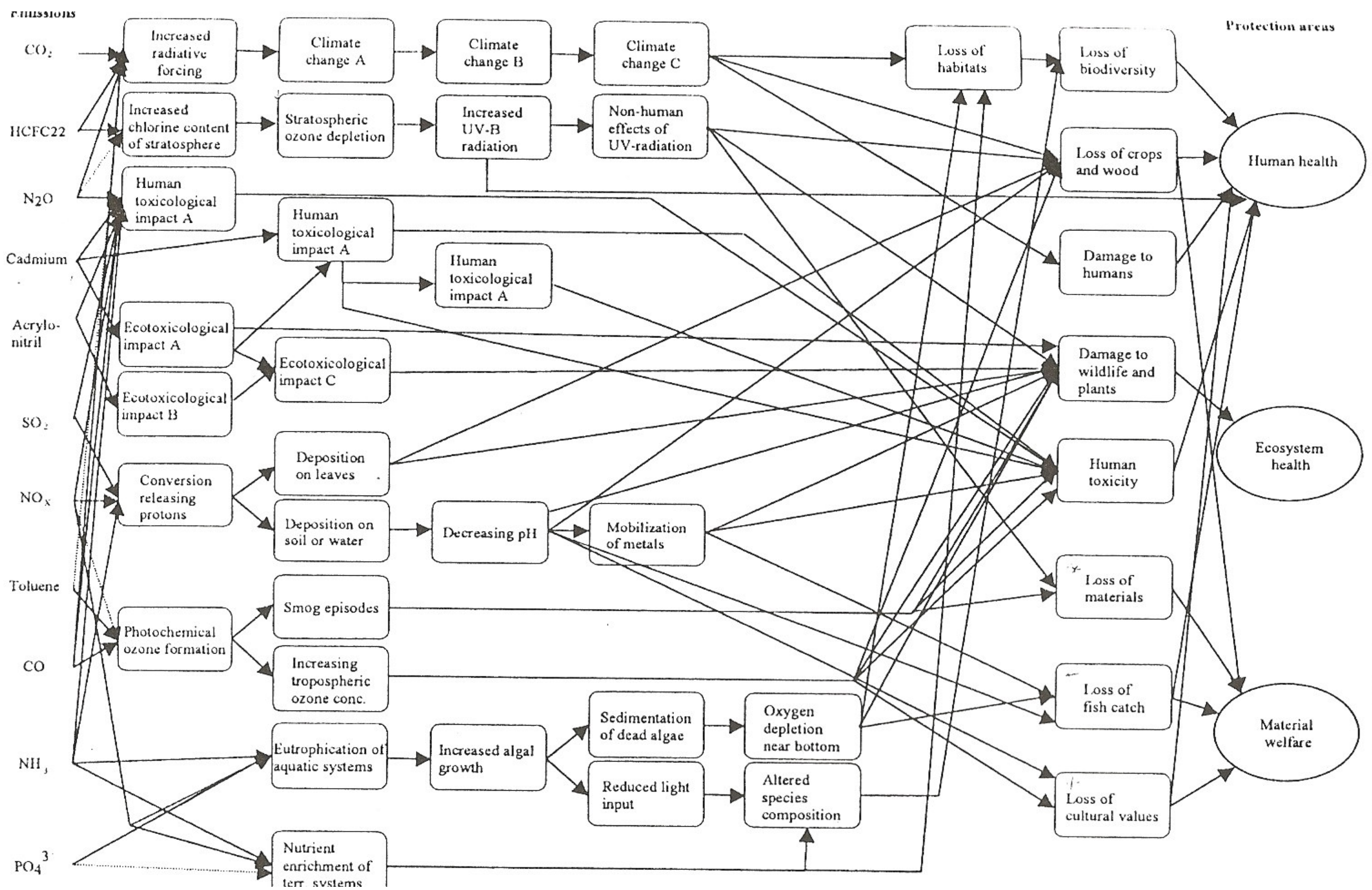


Figure 2.2 : Cause-impact network for environmental emissions [26].

Photochemical oxidants are formed by the reaction of nitrogen oxides with Volatile Organic Compounds (VOCs) under the influence of UV light [24].

The most important sources of winter smog, which occurs mainly in Eastern Europe are SO_2 and SPM (suspended particulate matter, or small dust and soot particles). This form of smog achieved notoriety in 1952 when it caused an estimated 4000 deaths in London [31].

2.1.3.2 Characterization

The potential contributions from the emissions of the life cycle are calculated for all of the impact categories in the characterization step [24]. Impact characterization uses science-based conversion factors, called characterization factors, to convert and combine the LCI results into representative indicators of impacts to human and ecological health. Characterization factors are commonly referred to as equivalency factors. Characterization provides a way to directly compare the LCI results within each impact category [21]. As an example, global warming potential GWP is measured relative to the effect of 1 kg CO_2, photochemical oxidant formation is measured relative to the effect of 1 kg ethene [24].

The potential contribution EP(j) to a given impact category j is calculated from following generic Equation 2.1, where $EF(j)_i$ is the substances equivalency factor for the environmental impact category j, Q_i is the magnitude of the emission i, [7]

$$EP(j) = \sum_i EP(j)_i = \sum (Q_i \cdot EF(j)_i) \qquad \textbf{(2.1)}$$

Equivalency units related with Ecoindicator95 method is given in Table 2.1.

Table 2.1: Equivalency units.

Impact Category	Emissions
Acidification	kg SO_2 equivalent
Eutrophication	kg PO_4^{-3} equivalent
Global warming	kg CO_2 equivalent
Photochemical oxidant	kg Ethene equivalent
Winter smog	kg SO_2 equivalent
Carcinogenics	kg PAH equivalent
Heavy metals	kg Pb equivalent

The following calculations demonstrate how characterization factors are used to estimate the global warming potential (GWP) of defined quantities of greenhouse gases:

Carbon dioxide GWP Factor Value = 1 $kgCO_2Eq/kgCO_2$, Quantity = 1 kg CO_2

Methane GWP Factor Value = 21 $kgCO_2Eq/kgCH_4$, Quantity = 1 kg CH_4

$$EP(GWP) = Q_{CO_2} \cdot EF(GWP)_{CO_2} + Q_{CH_4} \cdot EF(GWP)_{CH_4}$$
$$EP(GWP) = 1kgCO_2 \cdot 1kgCO_2Eq/kgCO_2 + 1kgCH_4 \cdot 21kgCO_2Eq/kgCH_4$$
$$EP(GWP) = 22kgCO_2Eq$$

2.1.3.3 Normalization

Normalization, the scaling of all impact potentials and resource consumptions using a common reference, has two purposes [26]:

- to provide an impression of the relative magnitudes of the potential impacts and resource consumptions
- to present the results in a form that is suitable for the final weighting and decision-making

The normalization consists in dividing the impact potentials or resource consumptions by the corresponding normalization references. According to the EDIP method, the normalized environmental impact potentials, NEP, are thus calculated as in Equation 2.2 [26]:

$$NEP(j) = \frac{EP(j)}{ER(j) \cdot T} \qquad \textbf{(2.2)}$$

If the functional unit defines the duration of service as T years, the normalization reference is expressed as T · ER(j), where ER(j) denotes the normalization reference for 1 year for an impact category j [26]. The EDIP method uses the population of people in the region for which the impact is assessed. This background impact is thereby expressed as impact per person per annum or person-equivalent abbreviated to PE. The normalized potentials NEP(j) are thus expressed in PE (Person equivalent), i.e. fractions of the impact from an average person's contribution to the total [32]. However, GaBi4 version, which we use doesn't include the EDIP method values and we also decided to use Ecoindicator95 method.

The first step in any interpretation consists of comparing the scores with another value. In Ecoindicator95, "inhabitant equivalent" is developed for this. The normalization method is used for one European citizen causes in a year. The values are normalized to average European. The effects are compared on the scale of inhabitant equivalents. Normalized scores are dimensionless and represents the part of effect of the average European causes in one year. For example, if score of greenhouse effect is 0.003, it means that it is a 0.003rd part of average European causes in one year [33, 34]. Normalization reveals which effects are large and which are small in relative terms. According to Ecoindicator95 method, $ER_{EI955}(j)$ denotes the normalization reference of an impact category j [35]. Equation 2.3 shows the calculation of normalized environmental impact with Ecoindicator95 normalization reference.

$$NEP(j) = \frac{EP(j)}{ER_{EI95}(j)} \quad \textbf{(2.3)}$$

The following calculations demonstrate how normalization is carried out.

GWP Normalization Factor Value = 13,106 $kgCO_2eq$,   EP(GWP) = 22 $kgCO_2eq$

$$NEP(GWP) = \frac{EP(GWP)}{ER(GWP)_{E95}}$$

$$NEP(GWP) = \frac{22kgCO_2eq}{13{,}106kgCO_2eq}$$

$$NEP(GWP) = 1.68E^{-3}$$

2.1.3.4 Weighting

The weighting step (also referred to as valuation) of an LCIA assigns weights or relative values to the different impact categories based on their perceived importance or relevance. Weighting is important because the impact categories should also reflect study goals and stakeholder values [21]. Weighting aims to rank, weight, or, possible, aggregate the results of different life cycle impact assessment categories in order to arrive at the relative importance of these different results [22].

Weighting may be considered to address three basic aspects [22]:

- to express the relative preference of an organization or group of stakeholders based on policies, goals or aims, and personal or group opinions or beliefs common to the group;
- to ensure that process is visible, documentable, and reportable, and
- to establish the relative importance of the results is based on the state of knowledge about these issues.

Even if the contributions to two different impact categories are equally large on normalization, this does not mean that the impact potentials are equally serious. The mutual seriousness of impact categories is expressed in a set of weighting factors with one factor per impact category. The weighting is performed by multiplying the normalized impact potential, by this weighting factor as given in Equation 2.4 [26].

$$WEP(j) = WF(j) \cdot NEP(j) \tag{2.4}$$

WEP(j) is the weighted potential environmental impact of j, WF(j) is the weighting factor for impact category j, and NEP(j) is the normalized potential environmental impact of j. Values are represented as Pt (Ecoindicator point). Weighting is based on distance to target principle. The seriousness of an impact was judged by the difference of the current and target level. Criteria for target levels are; one excess death per million per year, 5% ecosystem degradation and occurrence of smog periods [31,33,34]. According to Ecoindicator95 method, weighting factors is given in Table 2.2

Table 2.2: Weighting factors of Ecoindicator95 [31].

Effect	Weighting Factor
Greenhouse	2.5
Ozone layer	100
Acidification	10
Eutrophication	5
Summer smog	2.5
Winter smog	5
Pesticide	25
Heavy metals in air	5
Heavy metals in water	5
Carcinogenic substances	10

2.1.3.5 Interpretation

The final step of the impact assessment is the interpretation. Life cycle interpretation is a systematic technique to identify, quantify, check, and evaluate information from the results of the LCI and the LCIA [21]. Here, the results of the impact assessment are interpreted in relation to the goal of the LCA [7]. The outcome of the interpretation may be a conclusion of the study serving as a recommendation to the decision makers, who will normally weigh it against other decision criteria (like economic and social aspects). The interpretation may provide input to a further iteration, reviewing and possibly revising the scope of the study, the collection of data for the inventory, and impact assessment [26].

ISO has defined the following two objectives of life cycle interpretation [21]:

- Analyze results, reach conclusions, explain limitations, and provide recommendations based on the findings of the preceding phases of the LCA and to report the results of the life cycle interpretation in a transparent manner.
- Provide a readily understandable, complete, and consistent presentation of the results of an LCA study, in accordance with the goal and scope of the study.

2.2 Applications of LCA

On the page of European Commission, applications of LCA are listed as [36];

- Product development and improvement
- Process and service operation
- Strategic planning
- Technological impact assessment
- Public policy making
- Marketing

The use of LCA in the private sector varies greatly. This differentiation depends to a large extent on where a given company is situated in the product chain and on the key driver for the LCA activity, e.g. legislation or market competition. For business teams, the LCA tool should be used to understand the environmental issues associated with upstream and downstream processes as well as on-site processes. This understanding can be used for continuous improvement in reducing the impacts throughout the supply chain [37]. With the goal of producing greener, more environmentally friendly products, LCA is used in industry to [36]:

- Support methodologies or tools aimed at developing greener products, such as Design for Environment (DfE) or Design for Recycling (DfR)
- Compare different design options during product development
- Identify the most important environmental problems (hot spots) in the life-cycle of their own product (System Analysis) and of competitors products
- Document improvements in the environmental performance of products
- Select amongst suppliers in a green supply chain management
- Communicate the environmental performance of products or services, through the use of environmental labels and product declarations
- Quantifying indirect effects which occur outside the production site but are caused by the demand of products and services on site,
- Benchmarking sites to find optimization potentials.

LCA has a variety of applications in the companies. It is a tool to focus on the most substantial environmental impacts in the life cycle of a product but it has also a indirect positive influence on the bottom line of a company if it is used correctly. The following Figure 2.3 summarizes some of the applications of LCA and how the life cycle orientated environmental work can go hand in hand with increased earnings [38].

LCA can be used directly in marketing claims, either offensively (promoting a product's environmental superiority) or defensively (deflecting claims of competitors). The LCA can support marketing claims for existing products, or can lead to product redesign, which better positions the product with respect to offensive or defensive marketing claims. All such changes impact the company's bottom line by impacting sales by first impacting product image. Changes in product image can in turn impact the overall corporate image as well. Corporate image changes can feed back onto product image, and may also have an influence on employee morale, regulator relationships, and investor attitudes. Simply conducting LCAs for the ostensible purpose of environmentally improving products can be used directly in promoting the corporate image. Finally, LCAs may uncover opportunities for efficiency improvements or cost reductions [39].

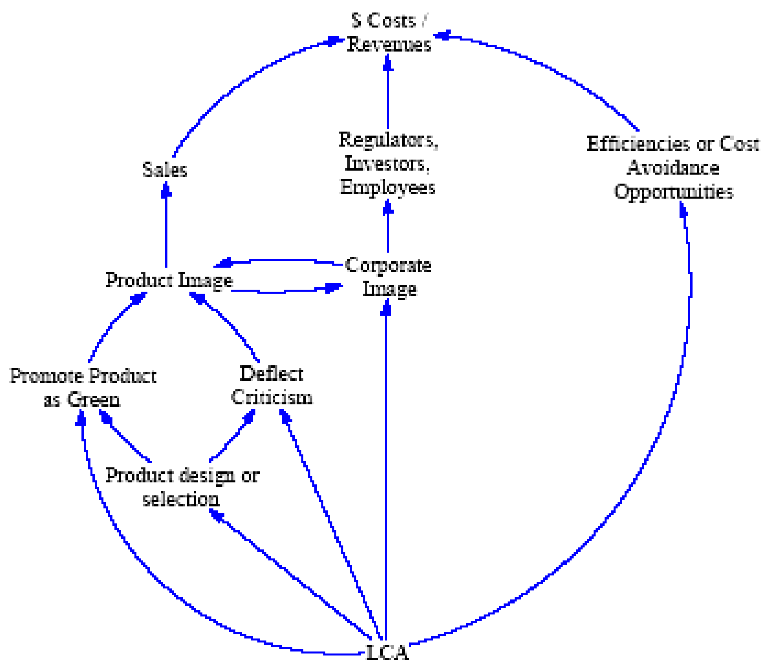


Figure 2.3 : Potential client impacts of an LCA [39].

The life cycle thinking approach is promoted in policymaking by for instance, the Integrated Product Policy (IPP) strategy. IPP is a voluntary approach and seeks to minimize the environmental effect of a product by looking at all phases of a product's life cycle and taking action where it is most effective [36].

The implementation of the IPP is attained with a variety of tools. These include measures such as economic instruments, substance bans, voluntary agreements, environmental labeling and product design guidelines. For example, waste management strategies, such as take-back responsibility for certain product types (e.g. cars and electronics) makes manufacturers liable to take their products back after ended use. Thus motivates them to design and construct the products with their disposal in mind [36].

2.3 GaBi4 LCA Software

GaBi4 software is a comprehensive tool to create life cycle balances. It is developed by the Institute for Polymer Testing and Polymer Sciences (IKP) of the University of Stuttgart in collaboration with PE Europe Gmbh. As a method for the assessment of the technical, economic and environment impacts of products, services and systems, comprehensive balances can be used to fulfill ecobalance (or Life Cycle Assessment) methods. GaBi4 is different from these methods due to its analysis method, which has been expanded to include technical, environmental, as well as socio-economic aspects [40].

The procedure of GaBi4 is standardized in the ISO 14040 series. Gabi is a modular system. This means that plans, processes and flows as well as their functions form modular units. It provides the user with the modular display of a product's life cycle. Individual life-cycle phases can be grouped in categories and can be processed separately from each other. The transparency of balance results is the major advantage of the GaBi4. It is possible to calculate the balances of different levels of detail. This facilitates the identification of weak points [40].There are different LCA softwares in the market, which are developed to evaluate the potential impacts of the products. The software-supported analysis is the base of the LCA today. The commercial and academical LCA softwares are continuously developed. Heidelberg Company compared the most well known ten LCA softwares. They were compared according to their functionality, flexibility, database, user friendliness, properties, service and cost. According to comparison, GaBi4 was found to be the best software available as showed in Table 2.3 [41].

Table 2.3: Evaluation of LCA tools [41].

	CUMPAN	EcoPro	EUKLID	GaBi	KLC-ECO	PEMS	PIA	SimaPro	Team	Umberto
Functionality	+	-	0	++	+	0	-	-	+	++
Flexibility	0	0	0	0	0	0	+	0	+	++
Database	0	-	0	+	-	0	--	+	++	-
User-friendliness	+	-	0	++	+	-	--	-	0	0
Software properties	+	0	0	0	+	0	+	0	-	-
Service	++	-	0	++	0	0	--	0	++	+
Cost	--	0	--	+	-	0	++	++	--	0

3. TRANSPORTATION AND ENVIRONMENT

"Facing Dilemma" is the idiom that is used to describe the "transport and environment" in the European Environment Agency (EEA) Report. There are ten key messages in the work of the EEA [1].

1. Freight transport volumes grow with no clear signs of decoupling from GDP. More goods are transported farther and more frequently. This results in increased CO_2 emissions and slows the decline in air pollutant emissions.

2. Passenger transport volumes have grown in most member states parallel to the economic growth.

3. Transport's energy consumption and their emission of greenhouse gases are increasing steadily because transport volumes are growing faster than the energy efficiency of different means of transport.

4. Harmful emissions decline, but air quality problems require continued attention.

5. Road transport has gained a greater and rising share of the freight market.

6. Air passenger transport grows, while the share of road and rail remain constant.

7. Developments in fuels contribute to emission reductions. Steps towards sulphur reduction are being taken. The share of biofuels is increasing, although currently reported shares are below the targets of the biofuels directive.

8. Car occupancy and lorry load factors decline in countries for which data are available. Growing car ownership, the decreasing average size of households and disperse spatial patterns are the main causes for low occupancy rates.

9. New technology can cut emissions and fuel consumption, but more effort is needed to achieve CO_2 targets.

10. Price structures are increasingly aligned with and yet well below external costs level. Further improvement of transport pricing is an opportunity to better balance the benefits and negative impacts of transport.

Growth of transport volumes has been shown to be closely linked to growth of GDP. Although there is a desire for economic growth, the negative impacts of transport are extremely undesirable. Most activities that contribute towards increases in GDP include an element of transport. Transport intensities of European countries are shown in Figure 3.1. Transport intensity is a measure of the amount of transport in relation to the size of the economy [1]. It is clear that the transport intensity of Turkey is worse compared to developed countries. It means that higher emission levels for the same production.

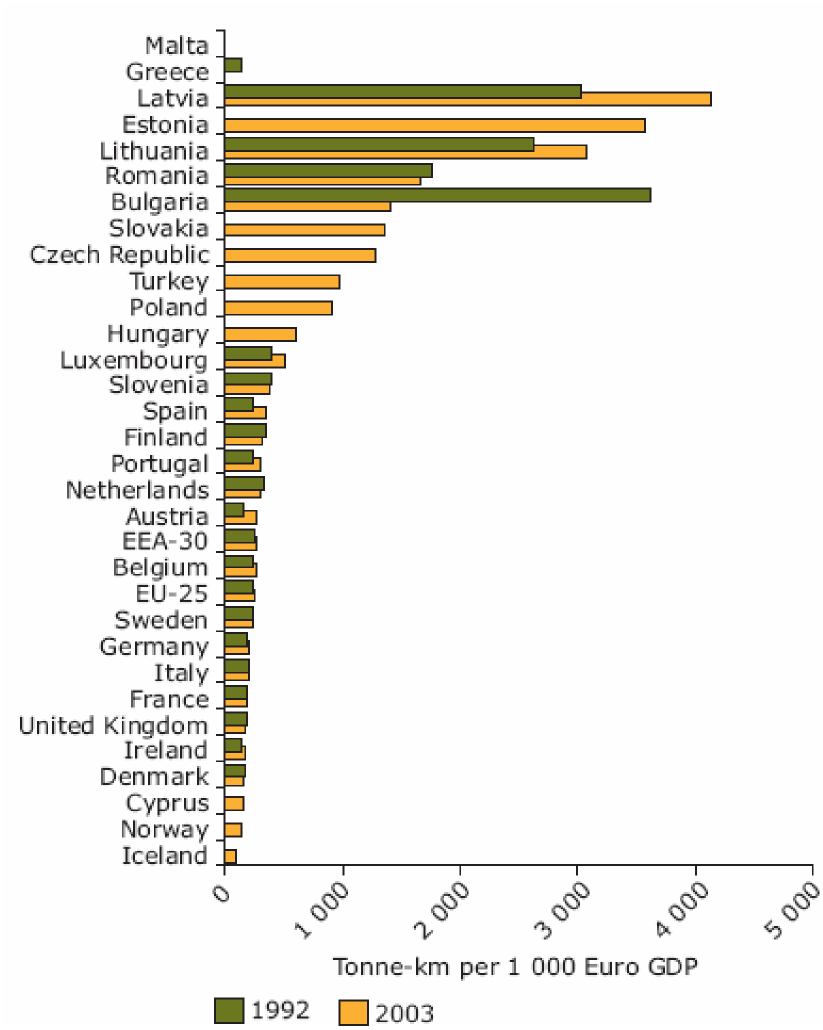


Figure 3.1 : Transport intensity [12].

The transport sector contributes to a variety of environmental problems, including poor air quality, noise and habitat fragmentation. Even if improvements can be made in some of these areas, we are far from seeing a solid and consistent development towards an environmentally sustainable transport system [42]. Transport emissions of greenhouse gases are presently growing. The main offender is the growth in transport demand, which is not being offset by the energy efficiency of vehicles [1]. Vehicle fleets are growing and gains in energy efficiency have been smaller than expected. Technology can deliver some of the greenhouse gas emissions reductions needed but not all. Behavioral changes are also needed to deliver net reductions. Rail transport emits on average less greenhouse gas per transport unit than road transport. However, rail transport's share of both passenger and freight traffic decreased to 5.8% and 10% respectively. Passenger air transport continues to grow significantly faster than passenger transport in general [2].

The EU Council has proposed that developed countries should commit to cutting their emissions by an average of 30% from 1990 levels by 2020. If no such agreement is reached, the EU Council is making a commitment to reduce its emissions by at least 20%. A proposed legislation on those targets was presented by the European Commission on January 23, 2008 [42].

Developing countries' challenges with respect to transport energy: rising oil prices are badly affecting their balance of payments; reliance on imported fossil fuels implies vulnerability and they are faced with the challenge of reducing greenhouse gas emissions [4]. There is a jam for the developing countries between the financing of investments and higher technology. Since, financing high technology fuel investments has higher costs, incomes of the developing countries decrease due to higher energy prices.

In 2005, the average car ownership level in the 32 EEA member countries reached 460 cars per 1.000 inhabitants, compared with 335 in Japan and 777 in the USA. Although Turkey has the lowest ownership rate (80 per 1,000 inhabitants), the largest growth was observed in Turkey compared to the new member states [2].

In the period from 1990 to 2005, the total freight transport demand of Turkey grew up to 60% and reached 163.130 million tkm (tonne km) Data include freight moved by road, rail and inland waterways. Road transport share in Turkey's total freight transport increased from 93.8% to 95.3% between 1996 to 2001 [2].

Transport volume's shares for European countries in 2003 are shown in Figure 3.2. In the period from 1990 to 2004, total passenger transport demand of Turkey grew up to 56% and reached 203.300 million pkm (passenger kilometer). During the same period, EEA average was 37% [2]. Road transport share of Turkey's total passenger transport was 87.3% in 2004. Table 3.1 shows the change of modal share in Turkey. It is a clear illustration of the privatization of transport in Turkey.

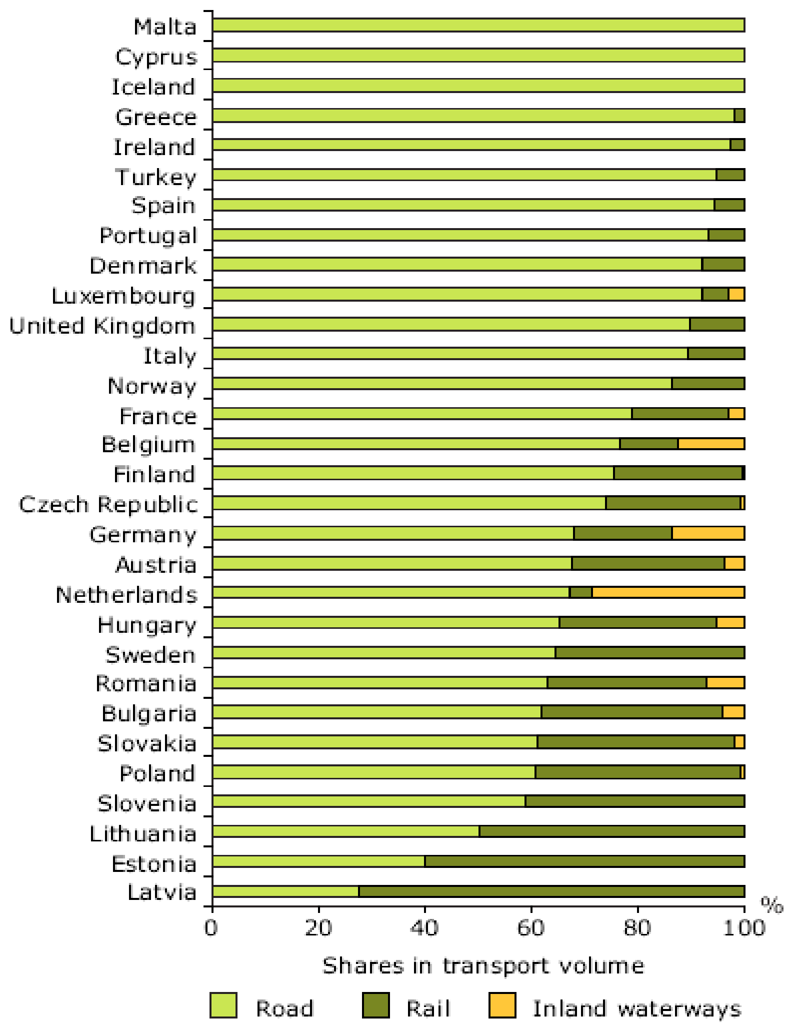


Figure 3.2 : Transport volume's shares in 2003 [1].

Table 3.1: Passenger transport demand by modal share (Unit %) [2].

	1990				1995				2000				2004			
	Rail	Bus	Private Cars	Air	Rail	Bus	Private Cars	Air	Rail	Bus	Private Cars	Air	Rail	Bus	Private Cars	Air
TR	4,9	64,8	26,4	3,9	3,8	55,8	34,3	6,2	3,1	46,3	41,9	8,7	2,6	38,5	48,8	10,1
EEA	7,4	12,1	73	7,5	6,2	10,4	73,9	9,5	6	9,7	72,4	11,9	5,7	9,1	72,3	12,9

Car ownership of Turkey increased from 51% to 80% in the fifteen-year period from 1990 to 2005, as shown in Figure 3.3. Lower car ownership of Turkey draws the huge transport market of future with increasing population and growing industry. Moreover, it is the ghost footprint of transport problems of the future.

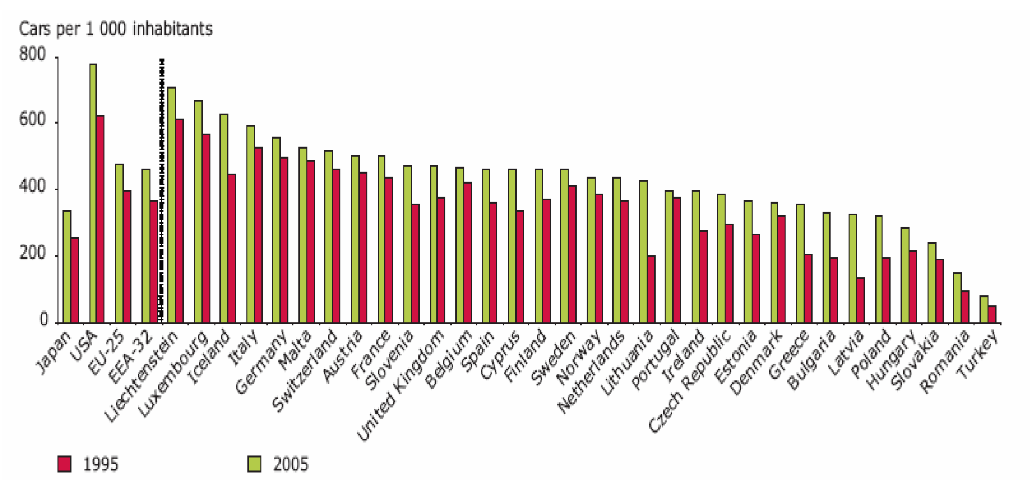


Figure 3.3 : Car ownership in EEA countries (Cars per 1.000 inhabitants) [2].

These results underline the importance of moving towards a more sustainable transport system that requires an integrated approach. Time for the developing countries like Turkey is the main constrain in managing this process. Problems should be considered well in advance and not just tackled at the end-of-pipe phase via emission regulation. Regional policy, structural policy, employment policy, agricultural policy etc. all have an impact on transport demand [1].

3.1 Environmental Effects of Transport Fuels

Road transport dominates the land transport market. It is generally the form of transport that is closest to the people. Thus, more people are exposed to its pollutants. Traffic is not the only source of the emissions behind these figures, but traffic does play an important role in the exposure of people to high concentrations of pollutants. Under the 'Clean air for Europe' program, it has recently been estimated that each year as many as 370,000 people die prematurely due to air pollution [1].

Since the beginning of the industrial age, human activities, mostly burning of fossil fuels, land use changes and agriculture have been the principal sources for observed increases in the atmospheric carbon dioxide (up 30 %), methane (up 145%), and nitrous oxide (up 15%). The Intergovernmental Panel on Climate Change (IPCC) has concluded that these increases have had a discernable impact on the earth's climate and are believed to be responsible for a significant (1° to 2°F) increase in the average global temperature since pre-industrial times. Even if carbon dioxide emissions could be returned to 1994 levels, scientists have estimated that the atmospheric concentration of the gas would double by the end of the century. The precise consequences of continued GHG emissions are not well understood, but potential adverse consequences include major changes in precipitation and temperature patterns, increased catastrophic storm activity, and higher sea level [43].

During the period 1990–2004, global emissions of CO_2 increased by 27%, from 20,463 to 26,079 million tonnes CO_2 (Mt CO_2). Energy demand from the transport sector that is seen as an indicator of global transport emissions, increased by 37% over the same period. Moreover, greenhouse gas emissions from transport (excluding international air travel and maritime transport) increased by 27% between 1990 and 2005 in EEA member countries as a whole [2].

In EU-15 Member States, domestic aviation showed an increase of 44% between 1990 and 2005. Maritime transport is currently responsible for approximately 13% of the world's total transport GHG emissions [2].

In Turkey's case, the road transportation is responsible for 95.3% of the total freight transport according to 2001 data and road passenger transport constitute 87.3% of the total passenger transport according to 2004 data. Total greenhouse transportation gas emission of Turkey increased by 56% from 26 million tonnes CO_2 eq. to 41 million tonnes CO2 eq. in the period from 1990 to 2005. Amount of road transportation greenhouse was 35 million tonnes CO_2 eq. in 2005 and 39 million tonnes CO_2 eq. in 2006 [2, 44]. In Figure 3.4, trends in transport greenhouse gas emission are given for EAA member countries.

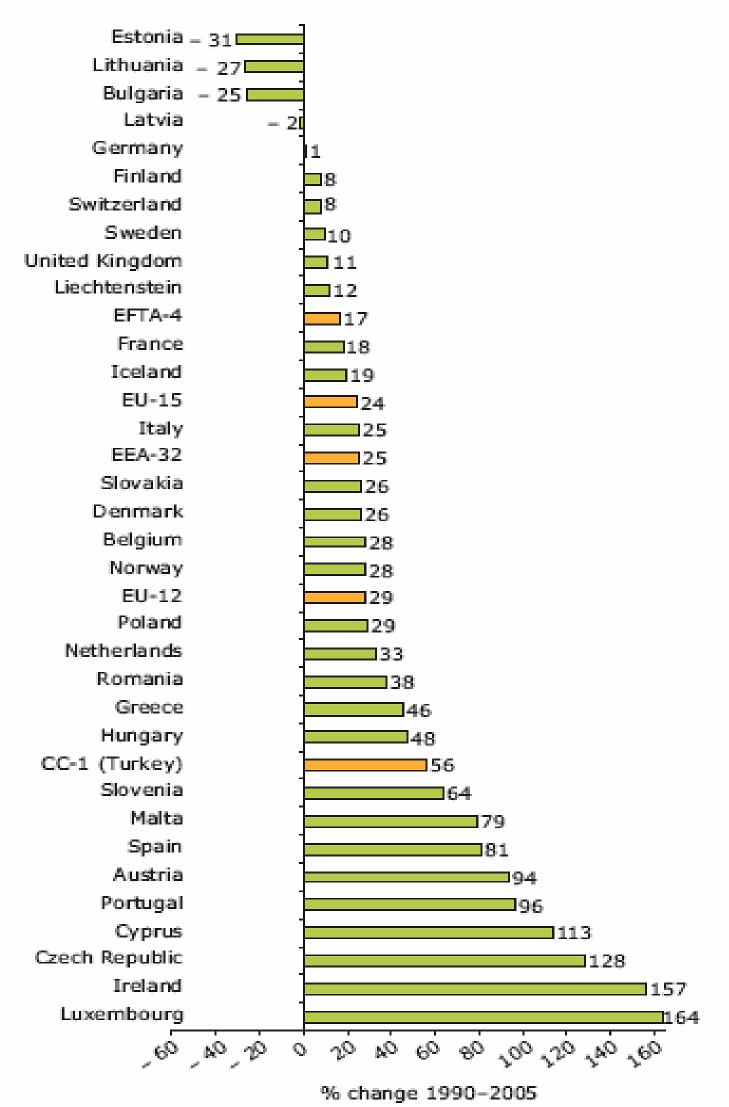


Figure 3.4 : Trends in transport greenhouse gas emission 1995-2005 [2].

In 2006, the total greenhouse gas emission of Turkey reached 341 million tonnes CO_2 eq. The total transportation greenhouse gas emission reached 46 million tonnes CO_2 eq. in 2006 and the road transport is 39 million tonnes CO_2 eq. of the total amount [44]. The total amount of greenhouse gas emission was also higher than the 2010 estimations of EEA, which was 340 million tonnes CO_2 eq. according to report published in 2007 [45].

Concern over air toxics from mobile sources, including benzene, formaldehyde, and 1-3 butadiene, also will affect choice of technologies for future vehicles. Emissions should be a major consideration in planning of the future [43]. Figure 3.5 shows the range of emissions per passenger-kilometer for different mode choices. The majority of EEA member countries observed an increase in greenhouse gas emissions from transport, due to an increases in transport movements arisen from behavioral reasons [2].

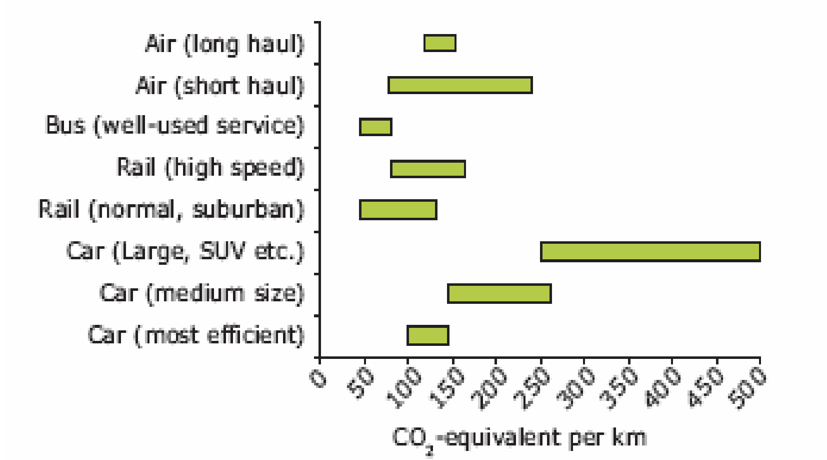


Figure 3.5 : Range of emissions per passenger-km for different transportations [2].

3.2 Bio-Alternative Fuels

Biofuels for transport produced from biomass are attracting considerable attention in Europe as a strategy to tackle climate change by decreasing greenhouse gas emissions from transport, to enhance energy security and respond to rising oil prices by substituting or blending petrol and diesel with biofuels, and to contribute to regional development by increasing employment opportunities and diversifying activities for farmers through energy crops [14]. The transportation sector is often linked with local air pollution. Substitute use of some biofuels could reduce emissions, and individual biofuels may have specific environmental advantages. In this respect, however, modern reformulated gasoline and diesel do meet present strict requirements [3].

Biofuels are compatible liquids with current vehicles and can be blended with current fuels. They share the long-established distribution infrastructure with little modification of equipment. In fact, low-percentage ethanol blends, such as E10 (10%

ethanol by volume) has almost no incompatibility with materials and the equipment. Biodiesel is currently blended with conventional diesel fuel in many OECD countries, ranging from 5% in France to 20% in the US, and is used as a neat fuel (100% biodiesel) in some trucks in Germany [6].

Recent events around the world have once again put energy security, and in particular oil import dependence, at the top of energy agendas in International Energy Agency (IEA) countries [6]. At present, biofuels make up less than 1% of total road transport fuel consumption, while petrol and diesel cover 98%. The remaining 1% is mostly covered by gas [1]. The emergence of global climate change as a critical energy and environmental policy issue has heightened awareness that combustion of greenhouse gas emitting fossil fuels imposes risks for the planet. Biofuels may provide a partial solution to each of these problems, by displacing oil use in transport and by reducing greenhouse gas emissions per liter of fuel consumed [6].

A key question for biofuels is how much CO_2 and other GHG emissions are released during all phases of fuel production. In some cases, emissions may be as high or higher than the net GHG emissions from conventional fuel vehicles over the conventional fuel cycle. Estimating the net impacts of using biofuels on oil use and GHG emissions is a complex issue and requires an understanding of fuel compositions, fuel production methods, combustion processes and related technologies throughout the full "fuel cycle", from biomass feedstock production to final fuel consumption [6].

Although biofuels are expected to play an increasingly important role to reduce fossil fuels depletion and emissions, they are not carbon neutral as there are emissions related to tilling, harvesting and fertilizing. Biofuels also require large areas of land for production and compete with other land uses such as extensive farming or forestation [1]. Land requirements to achieve 5% displacement of both gasoline and diesel would require the combined land total of 21% of the US and 20% of the EU. A 5% displacement of gasoline in the EU requires about 5% of available cropland to produce ethanol, while in the US 8% is required. A 5% displacement of diesel requires 13% of US cropland and 15% of the EU. Land requirements for biodiesel are greater primarily because average yields are considerably lower than for the ethanol as illustrated in Figure 3.6 [6].

The high land requirements for biodiesel production are largely due to relatively low yields per hectare compared to ethanol from grain and sugar crops. These estimates could be lower if, for example, vehicles experience an efficiency boost running on low-level biofuels blends and thus require less biofuel per kilometer of travel [6]. In addition, the extent to which biofuels can displace petroleum-based fuels depends on the efficiency with which it can be produced. To demonstrate that a biofuel has a positive energy balance, i.e. more energy is contained in the fuel than is used in the production, a life-cycle approach must be employed [25].

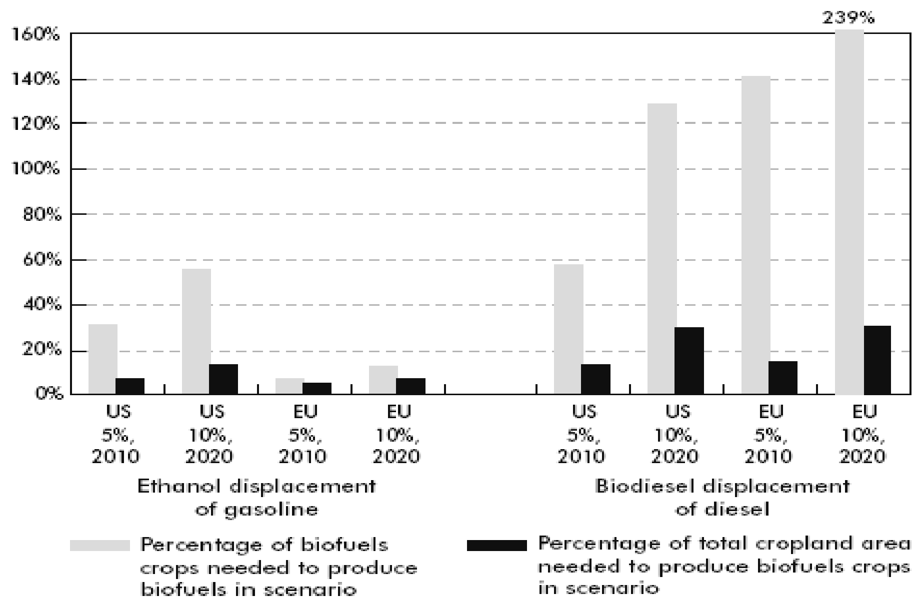


Figure 3.6 : Crops and croplands to produce biofuels under 2010/2020 scenarios[6].

3.2.1 Biodiesel

Biodiesel is the name given to a renewable fuel produced from fats and oils. It consists of simple alkyl esters of fatty acids, typically the methyl esters. Biodiesel can be produced from any material that contains fatty acids. Fatty acids can linked to other molecules or present as free fatty acids. Thus, various vegetable oils, animal fats, waste cooking oils, and edible oil processing wastes can be used as feedstocks for biodiesel production. The choice of feedstock is based on such variables as local availability, cost, government support and performance as a fuel [46].

Biodiesel can be used in compression ignition diesel systems, either in its 100% “neat” form or more commonly as a 5%, 10% or 20% blend with diesel [6].

After the oil shortages of 1973 and 1979, the industry in Germany, France and Italy developed energy-saving, highly efficient engines. The first research activities regarding the development of alternative and renewable fuels were started. Commercially motivated Biodiesel-initiatives in Europe could be observed as early as 1988 predominantly in Austria and also in France, where the first industrial scale Biodiesel production plants went into operation in 1990/1991. In 1992, reform of the Common Agricultural Policy addressed European agricultural surpluses. This policy stimulated the use of set-aside land for non-food purposes. Low oil prices in the second half of the 90s have resulted in reduced interest of industry and politics in liquid biofuels. In 1998, the very disappointing contribution of 452.000 t coming from biofuels reflects the situation that specific policies had been adopted in four member states only: France contributed 58%, Germany 21%, Italy 18% and Austria 3%. In June of the same year, as a consequence of the 1997 Kyoto Conference on Climate Change, the EU-member states decided on a reduction of carbon dioxide emissions of 8,1 % on the basis of 1990 emissions for 2012, a goal which can only be realized with an important share of by using a considerable amount of renewable energy sources including liquid biofuels [47].

Production of biodiesel in Germany and Austria was initiated with small-scale plants but economic pressures have forced an increase in scale of plants for them to stay in business. The economies of scale which can be achieved from a larger plant have been found to be increasingly important and new units now are bigger and more efficient. New plants are typically constructed at a scale of 250,000 – 500,000 tonnes of biodiesel production. Smaller scale plants have diversified their feedstock to include a portion of used cooking oil in a bid to stay economic [48]. A biodiesel production process also involves well-established technologies that are not likely to change significantly in the future [6].

3.2.1.1 Production of biodiesel

A variety of different types of reaction configurations can be employed in biodiesel synthesis. They may involve inorganic acid, inorganic base or enzymatic catalysis, biphasic or monophasic reaction systems, and ambient or elevated pressures and temperatures [46]. The basic technology using vegetable oils is as follows [49]:

- The vegetable oil (or animal fat) is first filtered and then pre-processed to remove water and free fatty acids
- It is then mixed with alcohol (usually methanol) and a catalyst which causes the oil's triglycerides to form esters and glycerol
- These fractions are then separated and purified into glycerine and biodiesel
- The methanol from the biodiesel stream is recovered and reused.

Today biodiesel are generally produced with the base catalyzed reaction because it is the most economic [49]:

- Low temperature (66^{o} C) and pressure processing (138 kPa)
- High conversion (98%) with minimal side reactions and reaction time
- Direct conversion to methyl ester with no intermediate steps
- No exotic materials of construction are used.

Esterification is conducted by the addition of a monohydric alcohol to the oil in the presence of a catalyst. The triglycerides in the oil are transformed into fatty acid esters and glycerol. Normally methanol is the alcohol used in this reaction. The catalyst promoting the reaction may be acid or alkali. In most modern plants, the preferred catalyst is alkali for the main esterification process but, a pre-esterification step may be used with an acid catalyst for the conversion of free fatty acids. This reaction will take place at room temperature and the esterification reaction will result in separation of the heavier glycerol that has a density of 1.26 from the lighter ester. Separation can be conducted as a batch process in settling containers but in large plants, it is usually a continuous process involving tube settlers or other separation technology. The biodiesel may contain traces of soaps and some excess methanol and these are removed by centrifuge for the former and by distillation for the latter. The biodiesel is then ready for use [48]. Biodiesel process diagram is given in Figure 3.7.

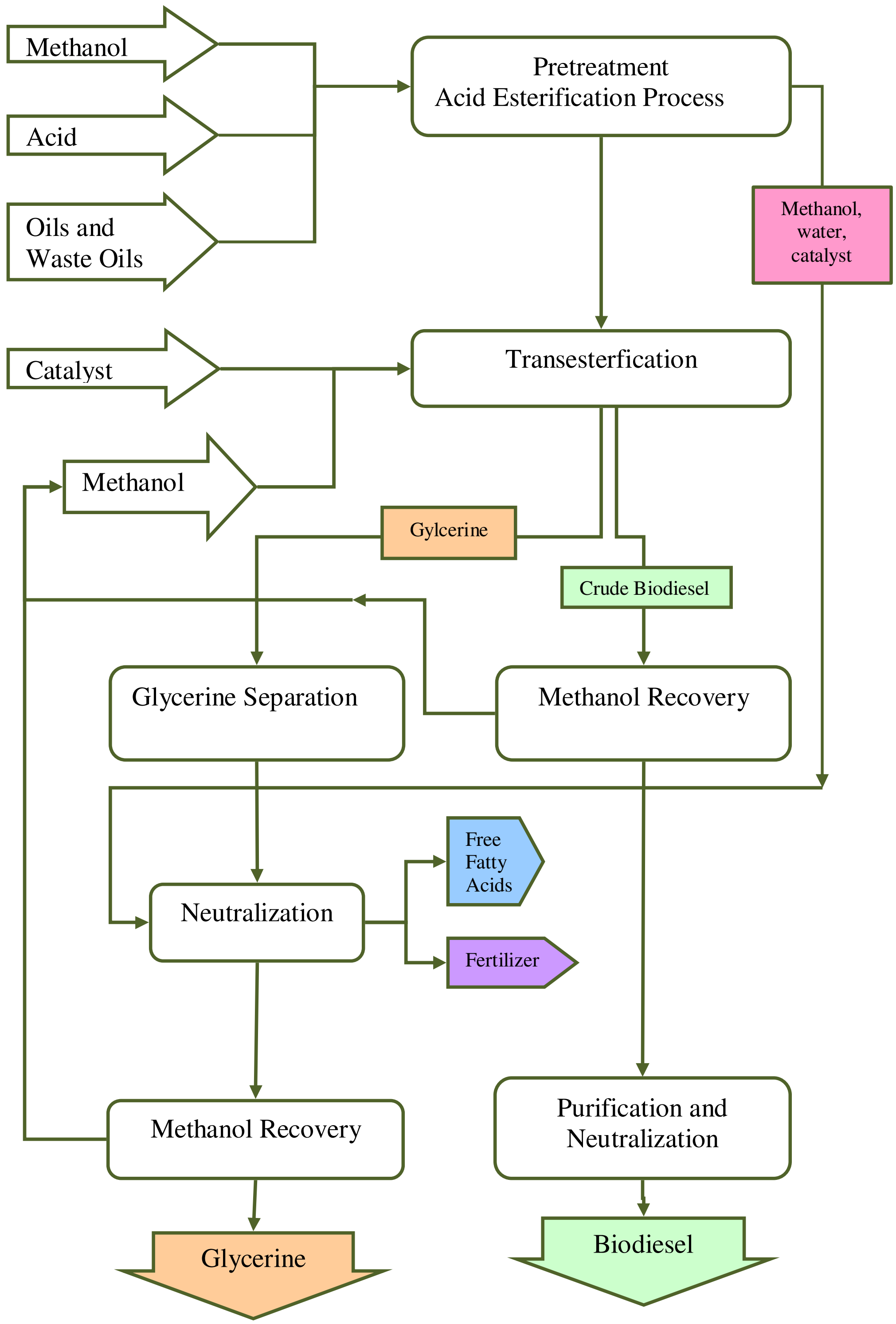


Figure 3.7 : Biodiesel process flow diagram.

Fatty acid methyl esters are products of the transesterification of vegetable oils and fats with methanol in the presence of a suitable catalyst. The stoichiometry of reaction requires 3 mol of methanol and 1 mol of triglyceride to give 3 mol of fatty acid methyl ester and 1 mol of glycerol as illustrated in Figure 3.8. This leads to three consecutive reversible reactions where monoglyceride and diglyceride are intermediate products. After the reaction, the glycerol is separated by settling or centrifuging and is purified to be used in its traditional applications (pharmaceutical, cosmetics and food industries). The methyl ester phase is also purified before being used as an alternative fuel to diesel [50].

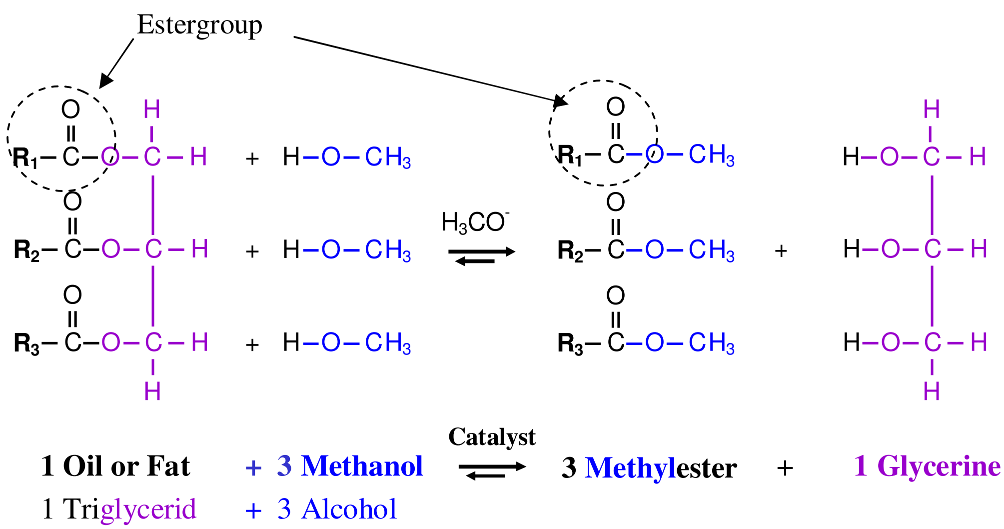


Figure 3.8 : Transesterfication reaction [51].

R1, R2, and R3 are long chains of carbons and hydrogen atoms, sometimes called fatty acid chains as illustrated in Figure 3.9.

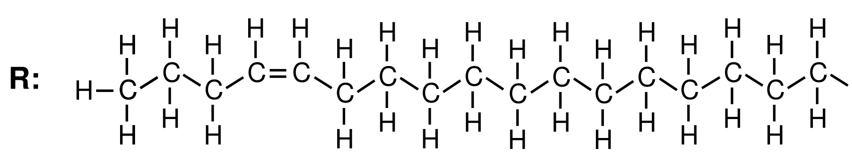


Figure 3.9 : Fatty acid chain [51].

The transesterification reaction can be catalysed by both homogeneous and heterogeneous catalysts. In turn, the homogeneous catalysts include alkalis and acids. The most commonly used alkali catalysts are sodium hydroxide, sodium methoxide (sodium methylate) and potassium hydroxide. The free fatty acid neutralisation can be avoided by using vegetable oil with a low free fatty acid content (>0.5%)

However, the most profitable raw materials (e.g. waste cooking oils and fats or low-value fats) usually have a high content of free fatty acid. Conversely, the saponification side-reaction only takes place when the catalyst is potassium or sodium hydroxide, because they contain the necessary hydroxide group (OH) for this reaction. Additionally, soaps increase the loss of methyl ester in the glycerol phase. However, the basic methoxides only have the hydroxide ion as an impurity. In this sense, they do not produce soap through trygliceride saponification. Commonly used alkali catalysts for transesterification reaction are illustrated in Figure 3.10 [50].

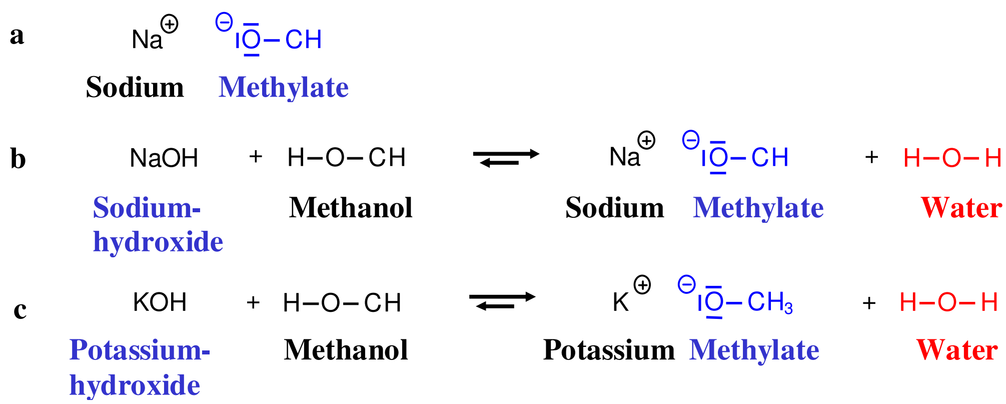


Figure 3.10 : Commonly used alkali catalysts [51].

It is common for oils and fats to contain small amounts of water and free fatty acids. Free fatty acids consist of the long carbon chains that are disconnected from the glycerol backbone. They are sometimes called carboxylic acids. If an oil or fat containing a free fatty acid is used to produce biodiesel, the alkali catalyst typically used to encourage the reaction will react with this acid to form soap as illustrated in Figure 3.11. This reaction is undesirable because it binds the catalyst into a form that does not contribute to accelerating the reaction. Excessive soap in the products can inhibit later processing of the biodiesel, including glycerol separation and water washing [52].

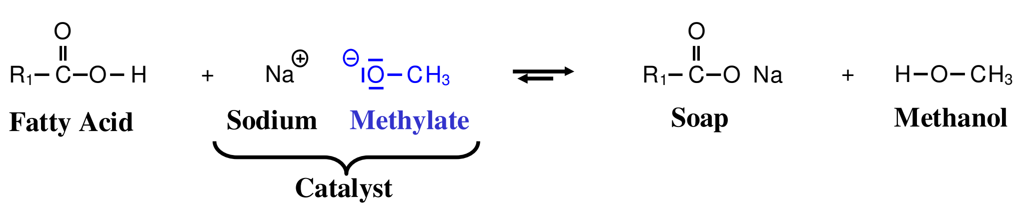
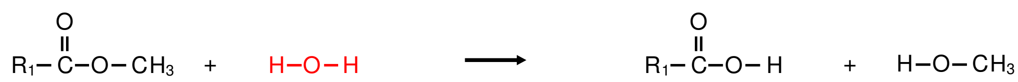


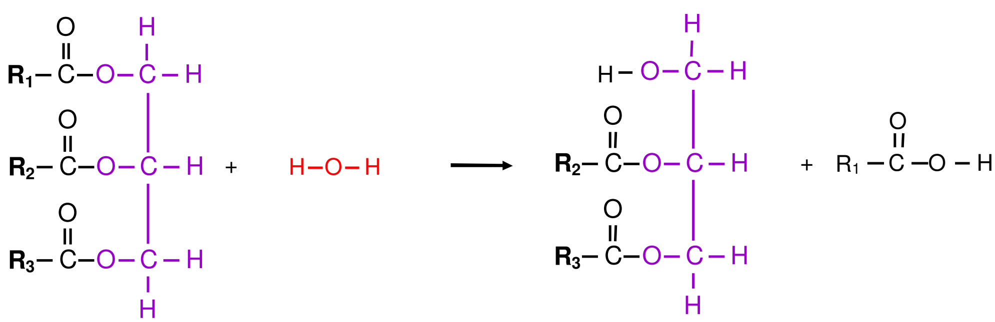
Figure 3.11 : Soap formation side reaction [51].

The absence of moisture in the transesterification reaction is important because as given in Figure 3.12, hydrolysis of the formed alkyl esters to FFA can occur. Similarly, because triglycerides are also esters, the reaction of the triglycerides with water can form FFA as illustrated in Figure 3.13 [53].



Methylester **Water** **Fatty Acid** **Methanol**

Figure 3.12 : Hydrolysis of methyl ester to form free fatty acids.



Triglyceride **Water** **Diglyceride** **Fatty Acid**

Figure 3.13 : Hydrolysis of triglyceride to form free fatty acids.

Depending the source of catalyst, methoxide ions can be obtained two different ways [52, 54]. One is the using pure alcoholate in a ready-to-use solution with alcohol (i.e with methanol) as in illustrated in Figure 3.14.

$$H_3CONa \longleftrightarrow H_3CO^- + Na^+ \qquad \text{(water cont.<0.2\% app.)}$$

Figure 3.14 : Methoxide ion in alcoholate solution [54].

Other is the preparing locally a catalyst solution within the biodiesel plant using hydroxides (i.e. sodium hydroxide and methanol) as illustrated in Figure 3.15.

$$NaOH + H_3COH \leftrightarrow H_3CO^- + H_2O + Na^+ \quad \text{(water cont.<11-13\% app.)}$$

Figure 3.15 : Methoxide ion in sodium hydroxide solution [54].

Using hydroxides to obtain the methoxide ions causes the water formation in the reaction environment. Side reactions related with water formation are given below in Figure 3.16 [52, 54].

Alcoholate	+	**Water**	⟶	Hydroxide	+	Alcohol
Triglycerides	+	Hydroxide	⟶	**Soaps**	+	Glycerine
Fatty Acids	+	Hydroxide	⟶	**Soaps**	+	**Water**
Fatty Acids	+	Alcoholate	⟶	**Soaps**	+	Alcohol

Figure 3.16 : Possible side reactions when using hydroxides as catalyst [54].

Most vegetable oils can be converted into biodiesel. In Europe, rapeseed is the preferred material for producing rape methyl esters (RME). In the United States, soy oil is the source for biodiesel, producing soy methyl ester, while in South East Asia, the readily available palm oil is the preferred raw material. Rapeseed is also important in the industry because of its by-product. After oil has been extracted, the by-product is a protein rich rapeseed meal used by the intensive livestock industry. Each raw material produces a biodiesel of differing specification. For example, palm oil produces an ester with a very high freezing point that could lead to difficulties in cold climates and would fail the European standard [48].

The biodiesel production process typically yields as co-products crushed bean "cake", an animal feed, and glycerine. Glycerine is a valuable chemical used for making many types of cosmetics, medicines and foods, and its co-production improves the economics of making biodiesel. However, markets for its use are limited and under high-volume production scenarios, it could end up being used largely as an additional process fuel in making biodiesel, a relatively low-value application [6].

3.2.1.2 Advantages and disadvantages of biodiesel

Some of the advantages of biodiesel include the following [13]:

- It is a renewable bio-based fuel and, as such, has lower life cycle CO_2 emissions than diesel derived from mineral oils.
- Neat biodiesel contains almost no sulfur. In a properly tuned engine, it is expected to lead to lower particulate exhaust emissions.
- The material is biodegradable and non-toxic.
- As an oxygenated compound, it reduces the non-soluble fraction of the particles.
- The PAH content of exhaust particles is generally reduced according to the conventional diesel (Some exceptions are possible) [55].
- The absence of sulfur allows a more efficient use of oxidation catalysts.
- In a mixture with low-sulfur diesel, biodiesel can act as a lubricity improver [13]. Biodiesel mixes well with diesel fuel and stays blended even in the presence of water. Even 1% blends can improve lubricity by up to 30%, thus reducing engine "wear and tear" and enabling engine components to last longer. Therefore, although biodiesel contains only about 90% as much energy as diesel fuel, with its higher burning efficiency (due to the higher cetane number) and its better lubricity, it yields an "effective" energy content which is probably just a few percentage points below diesel [6].

Some of the disadvantages of biodiesel include the following [13]:

- Constraints on the availability of agricultural feedstock impose limits on the possible contribution of biodiesels to transport.
- The kinematic viscosity is higher than diesel fuel. This affects fuel atomization during injection and requires modified fuel injection systems.
- Due to the high oxygen content, it produces relatively high NO_x levels during combustion.

- Oxidation stability is lower than that of diesel so that under extended storage conditions it is possible to produce oxidation products that may be harmful to the vehicle components.
- Biodiesel is hygroscopic. Contact with humid air must be avoided.
- The lower volumetric energy density of biodiesel means that more fuel needs to be used for the same distance traveled.
- It can cause dilution of engine lubricant oil, requiring more frequent oil change than in standard diesel-fuelled engines.
- A modified refueling infrastructure is needed to handle biodiesels, which adds to their total cost.

Table 3.2 presents findings from studies on the net energy savings, oil savings and well-to-wheels GHG emission impacts from using biodiesel from fatty acid methyl esters (FAME) rather than conventional diesel fuel (typically for truck applications). The European studies generally focus on rapeseed methyl ester, while the North American studies look at both rapeseed and soybean based biodiesel [6].

Table 3.2: Studies on biodiesel from oil-seed crops [6].

	Feedstock	Biodiesel production efficiency (litres/tonne feedstock)	Fuel process energy efficiency (energy in/out)	Well-to-wheels GHG emissions, compared to base diesel vehicle (per km travelled)	
				Fraction of base vehicle	Percent reduction
GM *et al.*, 2002	rape	n/a	0.33	0.51	49%
Levington, 2000	rape	1.51	0.4	0.42	58%
Levelton, 1999	canola (rape)	n/a	n/a	0.49	51%
Altener, 1996	rape-*a*	1.13	0.55	0.44	56%
Altener, 1996	rape-*b*	1.32	0.41	0.34	66%
ETSU, 1996	rape	1.18	0.82	0.44	56%
Levy, 1993	rape-*a*	1.18	0.57	0.56	44%
Levy, 1993	rape-*b*	1.37	0.52	0.52	48%
Levelton, 1999	soy	n/a	n/a	0.37	63%

Note: Where a range of estimates is reported by a paper, "*a*" and "*b*" are shown in the feedstock column to reflect this.
n/a: not available

The estimates for net GHG emissions reductions from rapeseed-derived biodiesel range from about 40% to 60% compared to conventional diesel fuel in light-duty compression-ignition engines. The range in estimates for biodiesel is explained partly by differences in conversion and energy efficiency assumptions and partly by disparities in assumptions regarding co-product credits [6].

One of particular concern to diesel producers are requirements to reduce the sulphur content of diesel fuel to meet various emissions requirements. Reducing the sulphur content also reduces fuel lubricity. Blending biodiesel can help, since it does not contain sulphur and helps improve lubricity. To reduce 350 ppm sulphur diesel down to 50 ppm, for example, requires a blend of more than 85% biodiesel. At current biodiesel production costs, refiners will likely prefer to cut the sulphur content of conventional diesel at the refinery [6].

3.2.2 Carbon cycle for rapeseed biodiesel

Rapeseed, like all other plants, uses the process of photosynthesis to capture light energy and convert it into chemical energy that the plant can utilize. Photosynthesis is the process in which plants absorb carbon dioxide and water, and use light energy from the sun to convert them into glucose. Photosynthesis reaction is illustrated in Figure 3.17. Oxygen and water are created as secondary products and released back into the atmosphere. The plant uses glucose, in combination with nutrients absorbed from the soil, for growth and development. The following equation describes the carbon-based process in terms of a balanced chemical formula [56].

$$6CO_2 + 12H_2O \xrightarrow{sunlight} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Figure 3.17 : Photosynthesis reaction.

In its most simple form the carbon cycle consists of the fixation of carbon and the release of oxygen by plants through the process of photosynthesis, then the recombining of oxygen and carbon to form CO_2 through processes of combustion or respiration. The CO_2 released by petroleum diesel was fixed from the atmosphere during the formative years of the earth. CO_2 released by biodiesel was fixed by plants in a recent year and will be recycled by the next generation of crops. In Figure 3.18 theoretical carbon cycle of rapeseed biodiesel is shown [56].

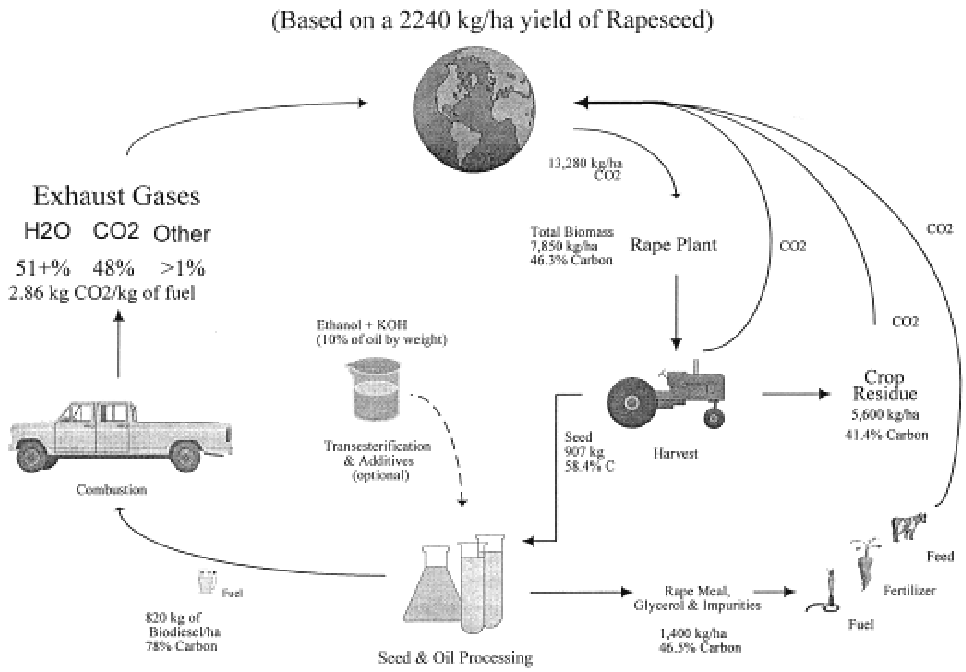


Figure 3.18 : Theoretical carbon cycle of rapeseed oil [56].

The plant takes in more CO_2 than is accumulated in the plant biomass. The carbon stored in the soil would continue to degrade and would eventually be released as CO_2 through biological activity. The residue (composed of approximately 2/5 (41.4%) of carbon) is generally left in the field, where tillage and soil conservation techniques incorporate it back into the soil as organic matter, where it can be processed by microorganisms. These microorganisms assimilate the carbon from the residue, retain some of it, and return the rest back into the atmosphere as CO_2 via respiration. During processing of rapeseed, the carbon cycle becomes considerably more sophisticated and complex, due the various number of processing techniques that may be utilized. The basic initial step for processing, is the extraction of the oil from the seeds. The seed has a carbon content of 58.4 %. After the oil is extracted, the resultant meal (with carbon content of 46.5%) may be disposed of in various ways. It can be used as a biomass fuel source, organic fertilizer, or feed for livestock [56].

3.3 Biodiesel in Turkey

The first biodiesel utilization attempt in Turkey was carried out in the 1934 by directives of Mustafa Kemal Atatürk. The project name was “Using Vegetable Oils in the Agricultural Tractor”. In the beginning of 2000, biodiesel became a focal point in the studies of Ministry of Energy and Ministry of Industry. In 2003, biodiesel was included in the Petroleum Market Law. First Turkish biodiesel standards were adopted in the same year. Today, auto biodiesel is allowed to be blended with diesel up to 5%. Blends up to 2% biodiesel are the free of tax [16].

During the elementary phase of market, hundreds of firms were set up to produce biodiesel. Only few of them today are continuing their production. Many of them were stopped by the Energy Market Regulatory Authority (EMRA) and Ministry of Environment and Forestry due to lack of product quality standards and environmental standards. However, thousands of small biodiesel production machines (50lt-1000lt) were sold to individual people until the regulation of market. Widespread environmental penalties were perpetrated at this period of time.

Currently there are 57 firms that have biodiesel production licenses. Most of them are not producing biodiesel due to the high oil prices. Eight of these are the firms that have licenses to produce biodiesel from waste cooking oil [57]. They also have problems related to the poor quality of waste cooking oils.

4. APPLICATION OF LCA FOR BIODIESEL

A comparative life cycle assessment of biodiesel-diesel blends (biodiesel blends) with diesel is studied within the scope of this study. Two blend ratios (B5 and B20) and two feedstocks are considered for biodiesel applications. Environmental burdens are analyzed according to comparison with fossil diesel. Commercial Gabi4 software package is used which satisfies for ISO 14040 requirements. Ecoindicator95 method is decided to evaluate the environmental impacts.

Rapeseed oil and WCO are chosen as feedstocks for biodiesel production. Lurgi Gmbh's biodiesel process is considered for production because of the higher biodiesel yield. Combustion data of fuels are entered the study according to data obtained from a comprehensive study on real transport conditions [55].

4.1 Goal and Scope Definition

The goal of this part of the study is to carry out LCA for conventional diesel and two different biodiesel blends, B5 and B20, produced from rapeseed oil and WCO.

4.1.1 Functional unit

The functional unit is chosen 100 km in defined city route. Biobus project performed in the Canada is used as basis for the fuel combustion process of our study [55].

Biobus project was a joint effort by the Canadian Renewable Fuels Association (CRFA), Federation of the Commercial Culture Producers of Quebec (FPCCQ, the Fédération des Producteurs de Cultures Commerciales du Québec), Rothsay/Laurenco (biodiesel producer) and the Corporation of the Transportation of Montreal (STM, Société de Transport de Montréal). In Biobus project, Biodiesel blends from WCO, tallow and vegetable oils were tested as a source of supply for public transit in city conditions. According to this study, it is noted that diesel fueled buses on city core routes consume an average 65 litres/100 km. Although this consumption is more than the amount of average European city buses, this project and the EPA study are the two main data sources which are available for the researchers. These two data sources include the combustion results which is based on the comprehensive studies also including the alternative feedstock usage. Additionally, Biobus study includes two different injection technology for diesel engines. One of them is equipped with older mechanical fuel injection, other is newer electronic fuel injection. However, EPA study is based on the diesel technologies that respond to the performance standards set from 1984 through 1997 which is relatively depend on the older technology vehicles according to Biobus project. Comparative evaluation of different feedstock alternatives is carried out by Biobus study. This is the other reason of why our study is focused on it [55,58]. However, there is no sulphur dioxide emission data in the Biobus study. Due to this reason LCA study which was performed in US, is used to simulate sulphur dioxide emissions [10].

100 km distance which is traveled on city core route by city bus is accepted as a functional unit. Bus is equipped with four stroke, 250 HP, 2200 rpm Cummings engines with electronic fuel injection. Using biodiesel affects engine performance and engine efficiencies. Due to these, fuel consumption is different for diesel and biodiesel blends. Engine performance is considered in preparation of the combustion processes of LCA [55]. Data including engine performance is given in Table B.11.

4.1.2 System boundaries

The life cycle of biodiesel is very complicated and serves the analyst many different application pathways. In this study, all stages of the fuel cycles are considered except for the byproduct usage and blending stage of diesel and biodiesel.

On the rapeseed biodiesel part of the study, two byproducts are considered for allocation, rape meal and glycerine. WCO biodiesel part of the study includes only glycerine byproduct. Economical allocation is implemented for the byproduct glycerine and rape meal according to market prices given in Table C.1. Appendix C includes details of the application criteria of allocation procedures. Byproduct straw obtained in the agriculture stage of LCA, are neglected in allocation approach.

Allocation of environmental loads with in the context of LCA has as a primary purpose to partition the loads generated within a system between the processes and products included in the system. The ISO definition is “Partitioning the input or output flows of a unit process to the product system under focus” [59].

Within ISO14041 it is stated that in any case allocation should be avoided by dividing the unit process to be allocated into two or more sub-processes or by expanding the product system to include the additional functions, related to the co-products (system expansion). Other principles that are to be considered if avoidance is not possible are technical causality, physical quantities (e.g. mass, volume or energy content), economic value and arbitrary number [11,59,60].

System expansion is better method than the allocation but it needs detailed process data. In our study, due to lack of data on the synthetic glycerine which is substituted by the biodiesel byproduct glycerine, allocation method is chosen to distribute environmental burden among co-products. Economical allocation is accepted instead of the mass allocation in the study, because mass allocation simply assigns the environmental emissions to the two co-products according to their relative mass outputs [11]. However, economical allocation shows the real target of the investment and gives importance of product according to the market conditions.

Real market data are available and are used to allocate rape meal and rapeseed oil. On the other hand, there is a chaotic situation in the biodiesel and glycerine market. Among the research on the prices, many of the biodiesel firms explained that they were out of production because of the higher vegetable oil prices and it was hard to estimate for biodiesel prices due to floating prices in the oil market. Some of the biodiesel producers also explained that they had problems with WCO biodiesel production because of the WCO qualities. Floating prices in the vegetable oil market cause the floating prices in the glycerine market, too. It depends on the continuous supply change of biodiesel to the market. Due to this negative situation, we try to evaluate most reliable price data according to the information from the biodiesel producers. Data used in allocations are given in Appendix C. Figure 4.1 shows the system boundaries for biodiesel production and consumption evaluation.

Conventional diesel life cycle is prepared with using GaBi4 allocated diesel process data. There isn't any byproduct output for diesel life cycle due to this reason.

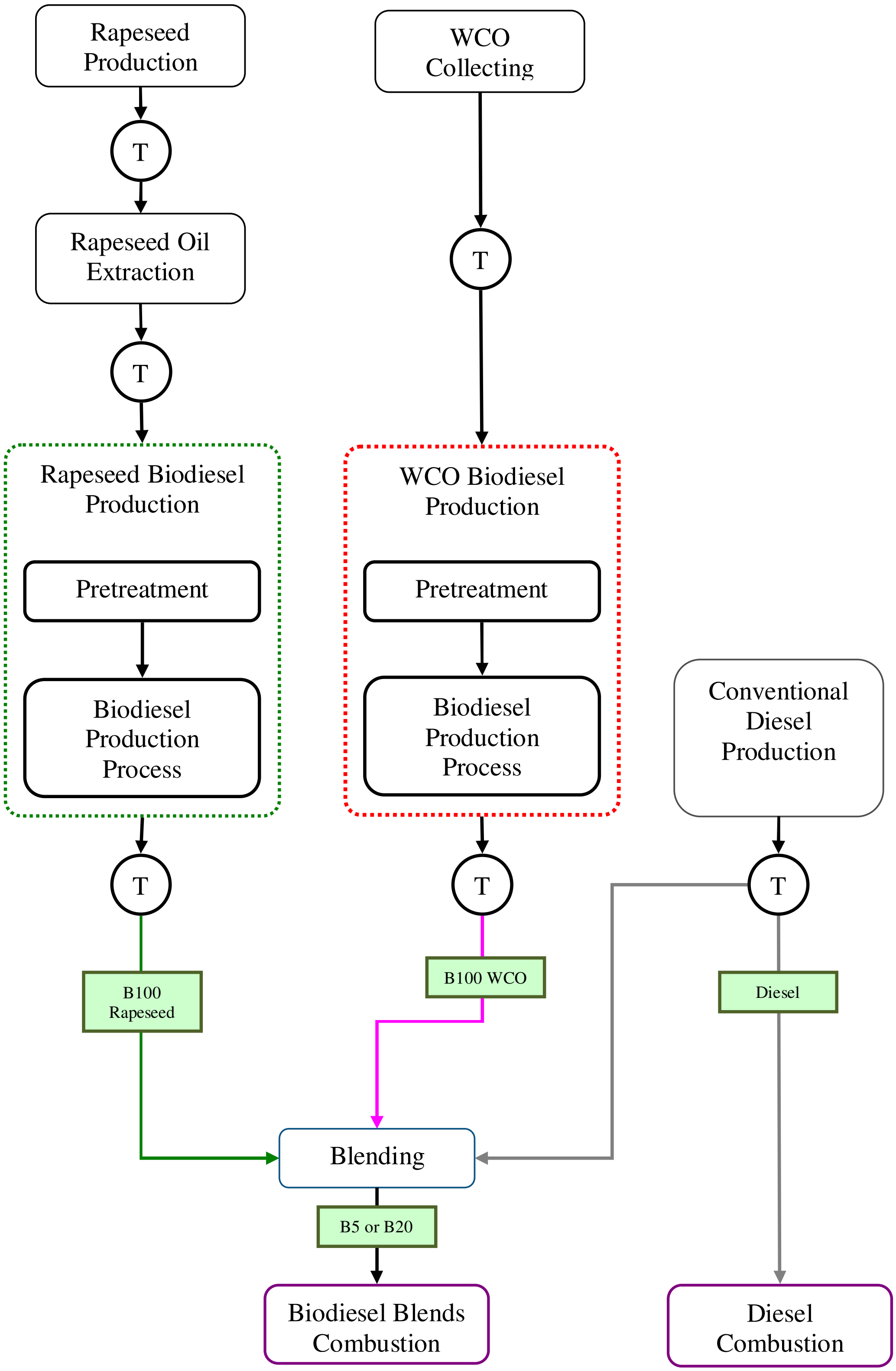


Figure 4.1 : System boundaries for biodiesel production and consumption evaluation (T=Transport).

4.2 Inventory

GaBi4 process data are tried to use every possible situation in the LCA. Additional data related to the production of biodiesel blends and diesel were collected from the country reports, scientific papers, database of the demo of Simapro7 LCA software and open media from web. Thus, the evaluated data include as much information from different sources as possible although some gaps are remaining. However, attaining the commercial data needs institutional relations and requires more time due to commercial risks associated with the biofuel industry investments. There are two main application pathways of biodiesel in Turkey. These are

- Rapeseed oil biodiesel
- Waste cooking oil biodiesel

Because of the higher oil yield, rapeseed is accepted as oil seed alternative for biodiesel production. There are many subplans in the LCA of biofuels. Gabi4 is a comprehensive tool for managing these subplans. In the study, all the subplans are prepared according to 1000 kg of product output. Gabi4 calculates these subplans according to mass balance criteria.

4.2.1 Inventory of rapeseed biodiesel

The main rapeseed biodiesel LCA stages are production of rapeseed, oil extraction, rapeseed biodiesel production and combustion of rapeseed biodiesel in city bus.

Main scheme of the rapeseed biodiesel B5 (B5 Rapeseed) and rapeseed biodiesel B20 (B20 Rapeseed) life cycles are shown in the Figure 4.2 and Figure 4.3. All subplans which are given in Figures A.1-A.5, are same for the B5 and B20 rapeseed. Plans that are given in the Figure 4.2, Figure 4.3, Figure A.2 and Figure A.5, are allocated according to the economical allocation. Process named as "Output (Process for Allocation)" is created due to the allocation procedures and it has no influence on the LCA. In the transport stage of the rapeseed and rapeseed oil, an average of 200 km pathways are considered. In the transport stage of biodiesel transport to fuel distributors, average 300 km pathway is considered. According to GaBi4 database, long distance truck which is 22 tonnes total capacity and 14.5 tonnes payload is accepted as a transport truck. It is also accepted that truck uses the 85% of its payload capacity. Inventory data are given in Tables B.1-B5, B.10, B.11 and C1.

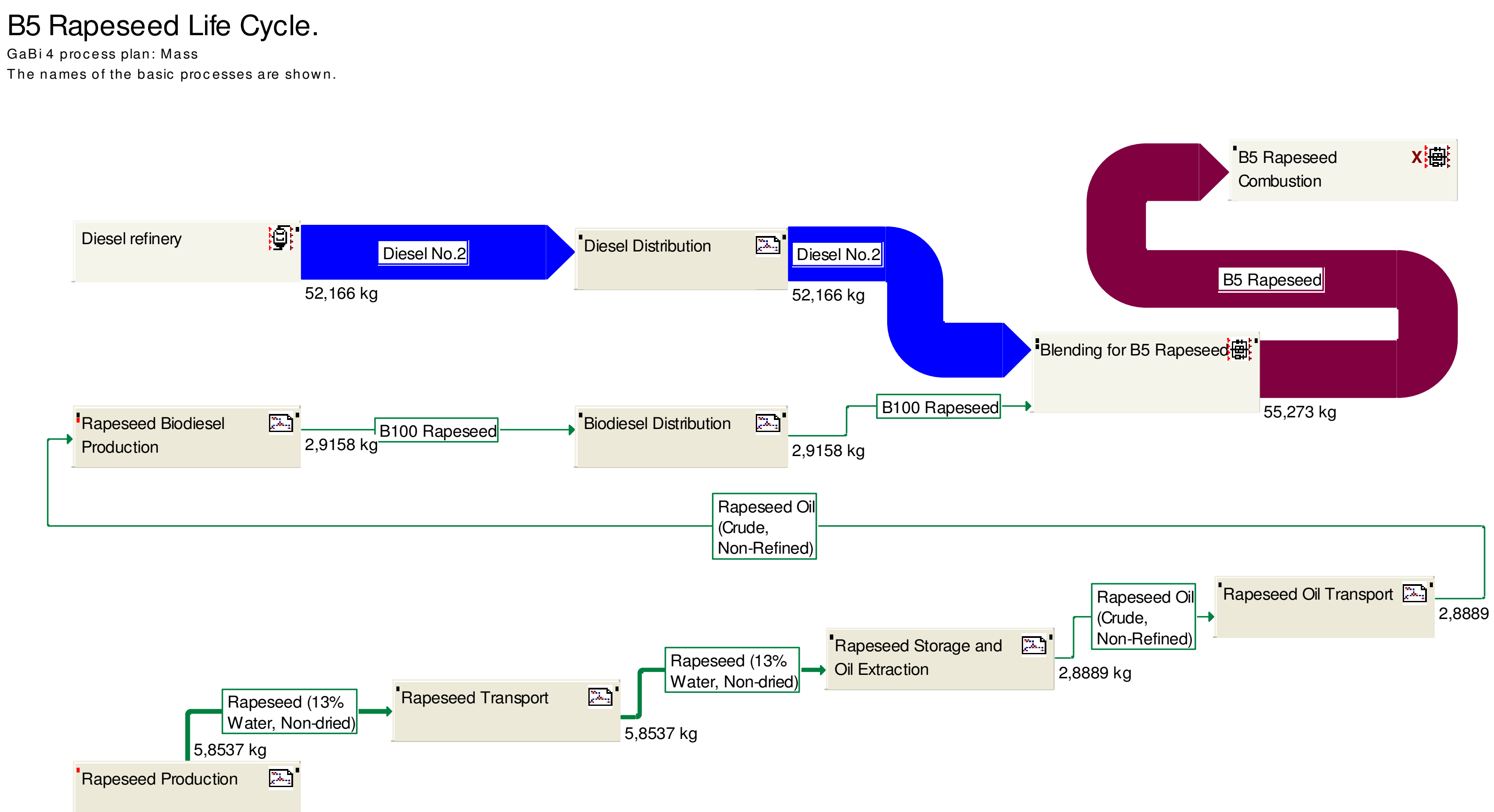


Figure 4.2 : B5 Rapeseed life cycle

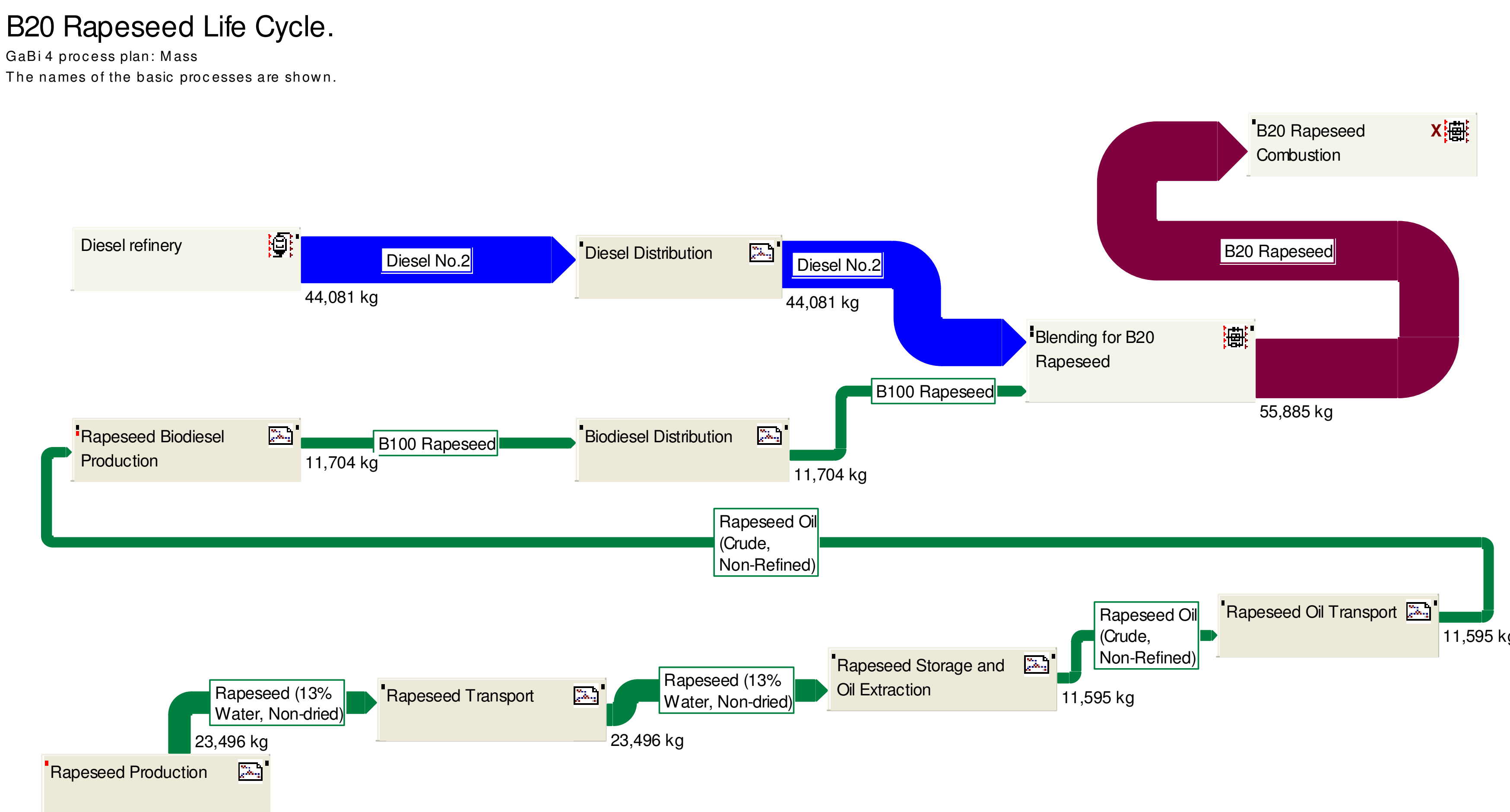


Figure 4.3 : B20 Rapeseed life cycle

4.2.2 Inventory of WCO biodiesel

The main LCA stages of the WCO biodiesel are WCO collecting, WCO biodiesel production and combustion WCO biodiesel in city bus. Main scheme of the WCO biodiesel B5 (B5 WCO) and WCO biodiesel B20 (B20 WCO) are illustrated in the Figures 4.4 and Figure 4.5.

All subplans that are given in Figures A.6-A.8, are same for the B5 and B20 WCO. Subplans are prepared to give 1000 kg of output like rapeseed biodiesel life cycle. Plans that are given in Figure 4.4, Figure 4.5 and Figure A.8, are allocated according to the economical allocation.

In the WCO collecting, average 350 km pathway is considered. It is accepted that 175 km of this distance is in forward way and 175 km in return way. Gabi4's small transporter truck process, which has 3.5 tonnes total capacity and 2 tonnes payload is accepted as WCO collecting truck. It is also accepted that it has 75% capacity in return way. Distribution stage of the WCO biodiesel an average of 300 km pathway is considered. WCO biodiesel Inventory data are given in Tables B.5-B.11.

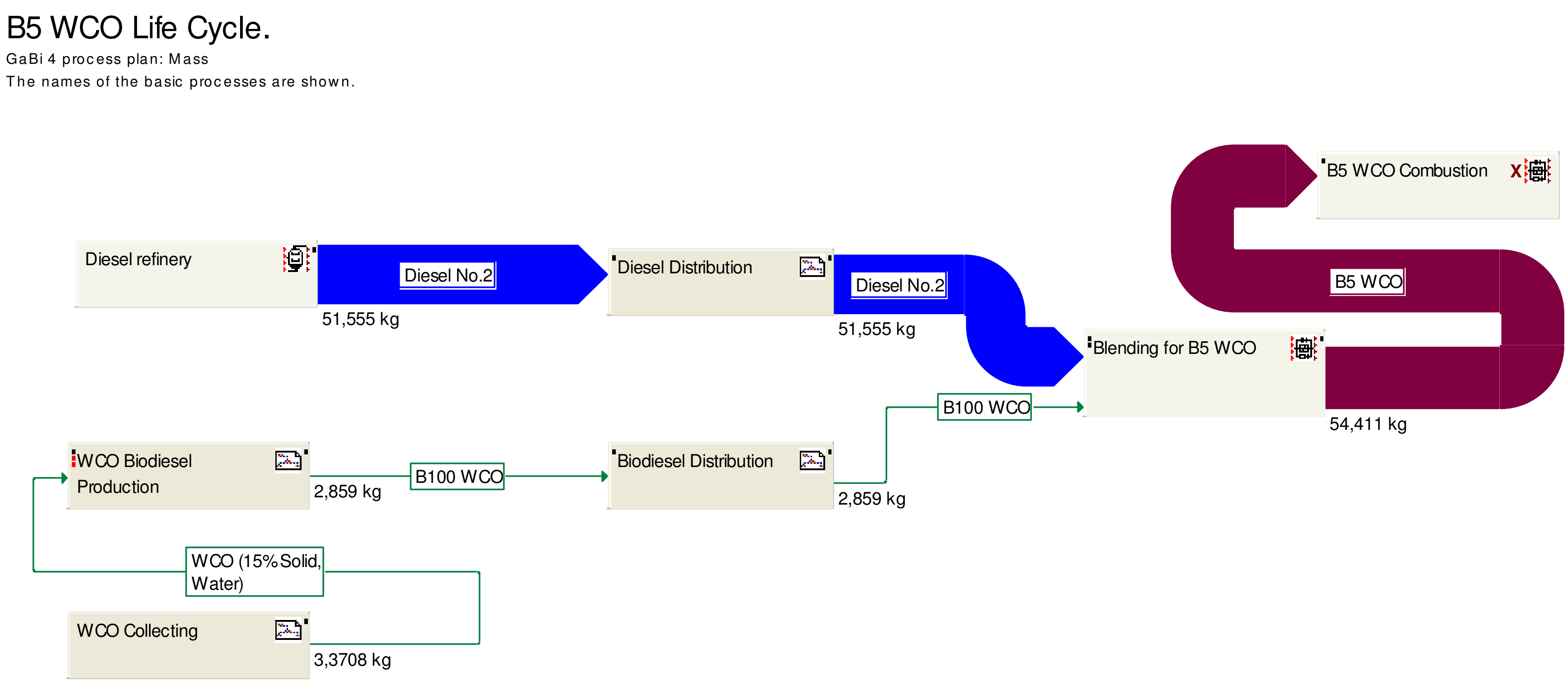


Figure 4.4 : B5 WCO life cycle

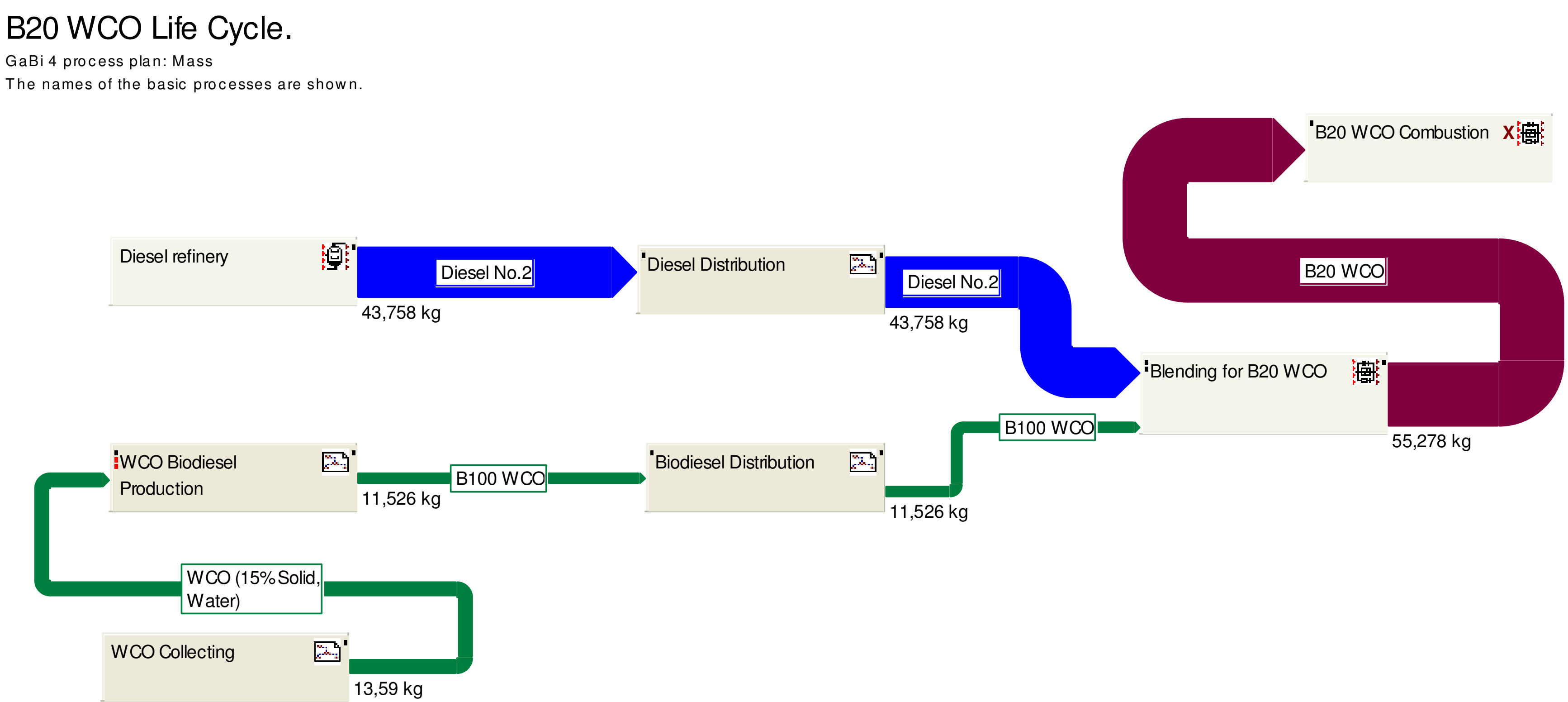


Figure 4.5 : B20 WCO life cycle

4.2.3 Inventory of diesel

The life cycle of conventional diesel is evaluated in the three stages that include diesel production from the refinery, diesel distribution and combustion of diesel. Diesel refinery process data, which is taken from the GaBi4 database includes all steps of the diesel life cycle to supply conventional diesel to the market. Diesel life cycle is given in Figure 4.6. Distribution stage of the diesel an average of 300 km pathway is considered. Truck process used to distribute the diesel is also same with biodiesel life cycle. Related inventory data are given in Tables B.10 and B.11.

The diesel refinery in the GaBi4 database produces 45.7 Mj/kg gross calorific value diesel. However, No.2 diesel used in the Biobus study which was carried out in the Canada, has a 43.5 Mj/kg gross calorific value and 500 ppm sulphur content. Depending on the crude petroleum oil market conditions, there are differences in calorific values of diesels from different countries. Petroleum oils, which are drilled in different regions of the world, have different characteristics and this affects the calorific value of the end product diesel. In addition to these, diesel used in Turkey has the gross calorific value of 45.2 Mj/kg. These variations are neglected in the analyze because there is not any alternative data that include comparative combustion among different biodiesel blends from different feedstocks [11, 55, 61].

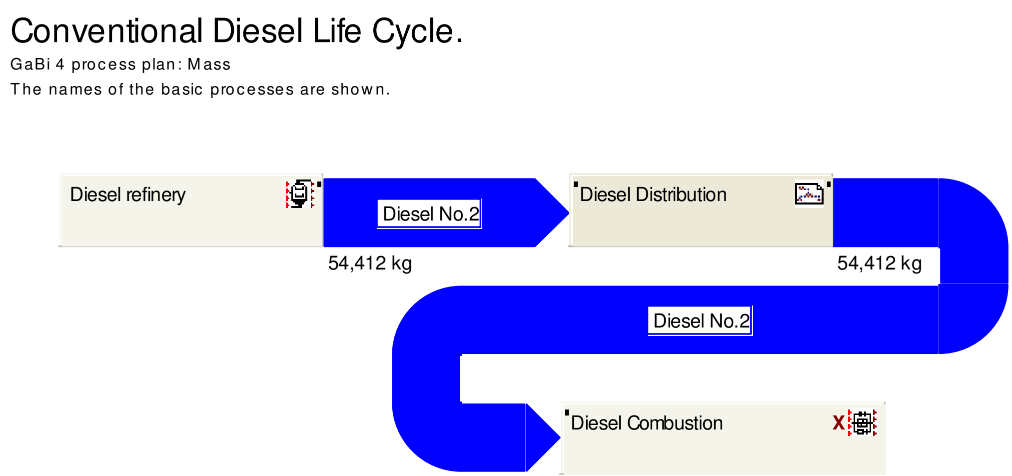


Figure 4.6 : Conventional diesel life cycle.

5. LIFE CYCLE IMPACT ASSESSMENT FOR BIODIESEL

The data summarized in the inventory phase are interpreted through characterization, normalization and weighting stages using GaBi4 software. As an initial step, prior to characterization, impact categories of acidification, eutrophication, global warming, winter smog, carcinogenic substances, heavy metals and photochemical oxidant formation are determined by taking into account the emissions from the entire life cycle of different biodiesels. Table 5.1 illustrates the emissions and the impacts of emissions on the environment.

Table 5.1: Classifications of some emissions to impact categories

Impact Category	Emissions
Global warming potential	CO_2, CH_4
Acidification potential	SO_2, NO_x, HCI, HF
Eutrophication potential	NO_x, NH_3, NH_4NO_3
Photochemical oxidant formation	Ethene, Propene, Butene
Winter smog	SO_2, TPM
Carcinogenic substances	PAH, Benzene
Heavy metals	Pb, Hg

5.1 Characterization

The streamline assessment of biodiesel blends and diesel are similar. GaBi4 calculates the contribution of the emissions to each impact category by using equation 2.1 and classifies the emissions into relevant categories. The equivalency factor expresses the substance's strength measured relative to a reference substance. In Figure 5.1 some of the equivalency factors from GaBi4 are given.

There are detailed analysis of LCA and comparisons in the Figures D.1-D.36. Figures are put in order of starting with basics and continued with details. Emissions that cause environmental impacts are given in detailed form.

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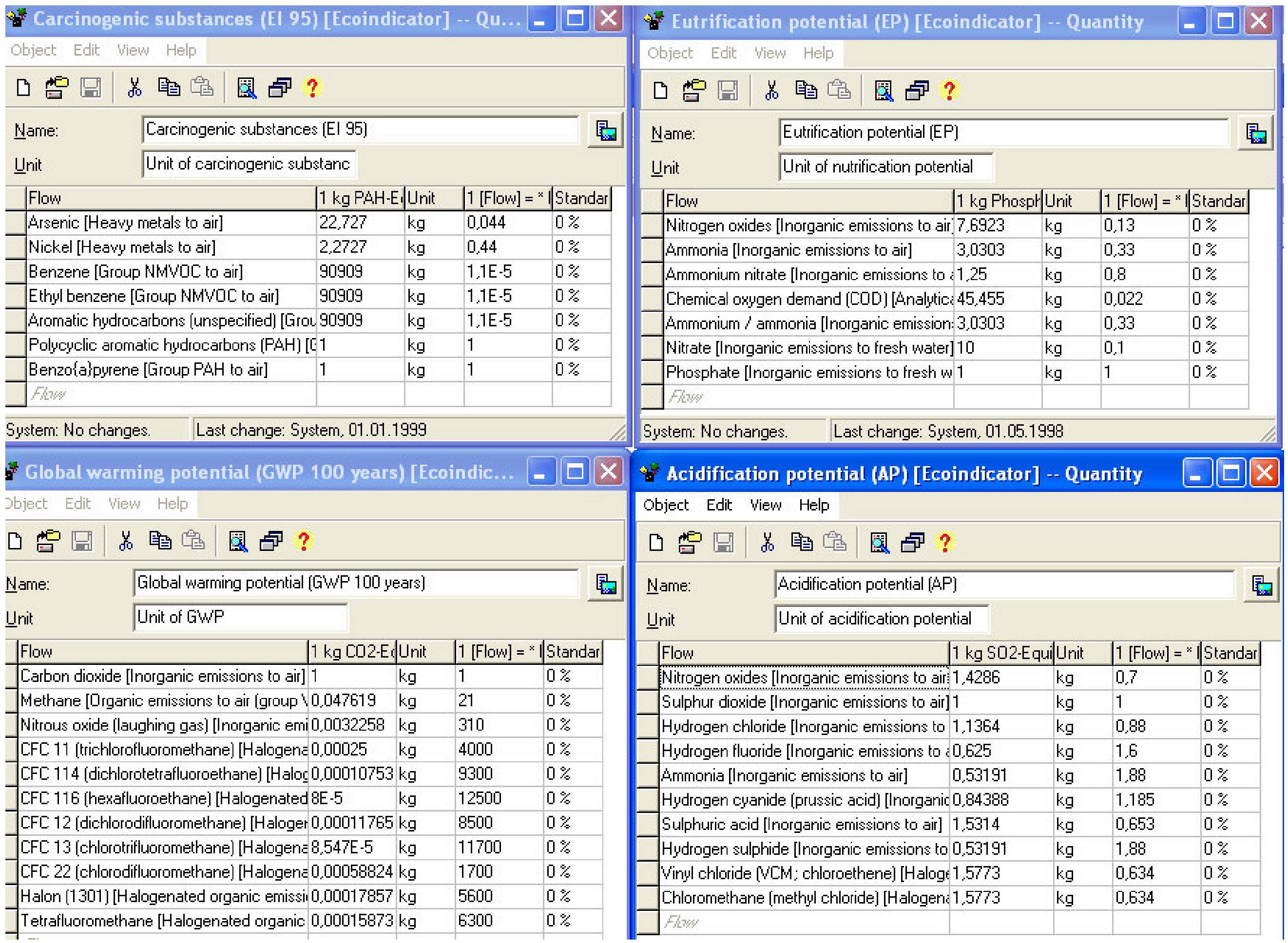

Figure 5.1 : Some of the equivalency factors used in the LCA

In Figures D.1- D.3, it is clearly indicated that WCO biodiesels have less global warming impact on the environment. Nitrous oxide emission of rapeseed production stage is as important as total carbon dioxide emissions of rapeseed life cycle. Carbon dioxide emissions of B100 rapeseed are distributed approximately equal in three stages; rapeseed production, rapeseed storage and oil extraction, rapeseed biodiesel production. If life cycles of rapeseed and WCO biodiesel blends are examined comparatively in Figures D.23 and D.30, it is understand that positive performance of WCO biodiesel depends the production stages of WCO biodiesel. WCO biodiesel has less production stages in its life cycle. However, it is also important that collecting of WCO is the most important stage of WCO biodiesel according to Figures D.30-D.36. Small transporters are used for the collecting of WCO. Average of 350 km pathway is considered for collecting of 1.5 tonnes WCO in big cities. Due to this, emissions related with WCO transportation gains importance. Solid and water content of WCO is another criterion. This ratio of the WCO must be lower to provide sustainable waste oil recycling and biodiesel production. If this ratio increases, transportation emissions of the WCO increase.

Acidification potentials of life cycles include air and water emissions as illustrated in Figure D.7. However, water emissions have no impact on the acidification potential. Figure D.24 shows that chloromethane is only in water emission, which causes acidification. Nitrogen oxides, sulphur dioxide and ammonia are the most important emissions. Ammonia emissions depend on the nitrogen fertilizer use in the cultivation of rapeseed. Nitrogen oxides and sulphur dioxide emissions that have the highest impact on the fuel life cycles, mainly depend on the combustion of fuels as illustrated in Figures D.5 and D.6.

Figures D.7 and D.8 show the eutrophication potentials of fuel life cycles. Nitrogen oxides and ammonia are the most important air emissions that cause the eutrophication potential as given in Figure D.9. Nitrate is an important emission as water emission illustrated in Figures D.9 and D.25. Chemical oxygen demand and ammonium are the other water emissions and they have no influence on the results. Rapeseed biodiesel has significance nitrate emissions in the cultivation stage of the rapeseed as shown in Figure D.25. It is also determined that diesel fuel has the remarkable nitrogen oxides emissions in the diesel production stage according to

Figure D.9. Combustion related nitrogen oxides emissions have the biggest impact on the eutrophication potential.

Biodiesel blends have less impact on the environment in term of photochemical oxidant formation as illustrated in Figures D.10-D.12. Diesel production in refinery causes significant photochemical oxidant formation on the environment according to Figure D.11. Non-methane volatile organic compounds are determined the emissions cause photochemical oxidant formation as illustrated in Figure D.12. Hexane is the important non-methane volatile organic compound which is emitted in the oil extraction stage of the rapeseed.

WCO biodiesel has positive environmental impact on the winter smog formation although rapeseed biodiesel has negative. Production stages of rapeseed biodiesel cause increase of particulates in the environment as given in Figures D.13- D.15. Figures D.27 and D.34 include detailed analysis of winter smog potentials of the rapeseed biodiesel and WCO biodiesel.

Except B5 WCO, all biodiesels have the lower emissions than diesel in terms of carcinogenic substances as illustrated in Figures D.16 and D.17. It depends on the combustion stage of B5 WCO. Polyaromatic hydrocarbons are most known carcinogenic substances in fuel's life cycles as given in Figure D.18. Nickel is another important carcinogenic substance which is emitted in the diesel production.

Heavy metal emissions of biodiesels depend on the diesel partition of their life cycles as illustrated in Figures D.19-D22.. Diesel production is most important heavy metal emission source. Heavy metal emissions to water are as important as the heavy metal emissions to air. It is determined that chemicals and energy resources used in rapeseed biodiesel life cycle cause significant effect on heavy metal emissions as given in Figures D.20 and D.29.

In Figures D.23 - D.36 impacts, which are related with B20 biodiesels are given in detailed form. Eutrophication and acidification potentials are the main environmental impacts, which influence the overall life cycle performance of rapeseed biodiesel according to figures.

5.2 Normalization

The contributions of life cycle stages to each impact categories are given in the characterization part of the LCA. At this step, normalization is implemented to facilitate comparison of the impact categories according to the common reference. GaBi4 calculates the normalized impact potentials according to Ecoindicator95 factors using an equation 2.3. Results of the normalization step are dimensionless. Normalized impact potentials of fuel life cycles are given in Figures 5.2 and 5.3. Results from the figures show that global warming potential, acidification potential, photochemical oxidant formation potential and eutrophication potential have the highest environmental impacts. However, normalization gives limited information about the importance and seriousness of environmental impacts. Further step is necessary to evaluate these results. This step is weighting. Importance of the impact potentials are closely related with the conditions of the life cycle area. Due to this, the scores obtained in the normalization step are evaluated according to importance of impact potentials at the next section.

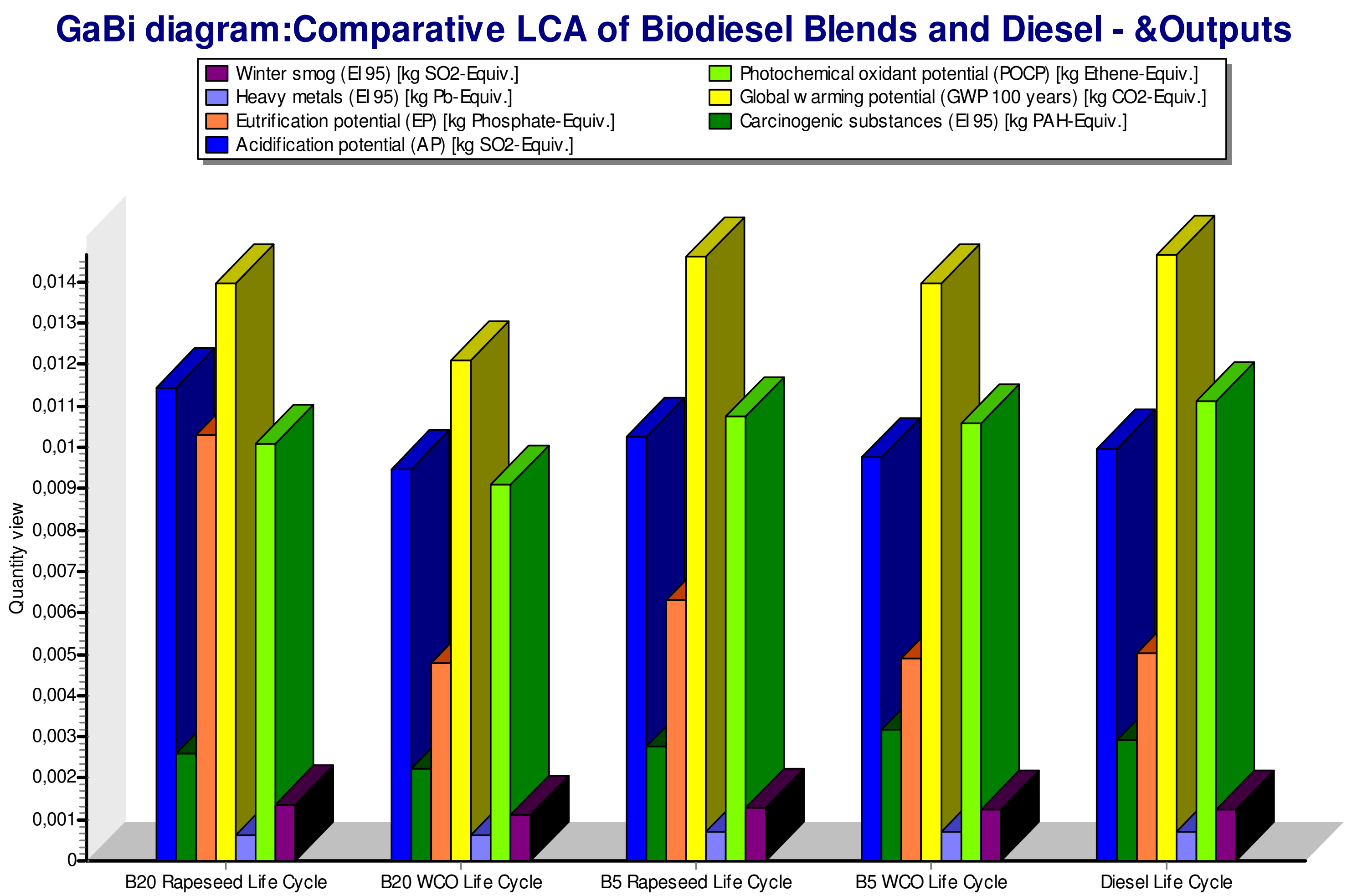

Figure 5.2 : Normalized impact potentials of fuels according to Ecoindicator95.

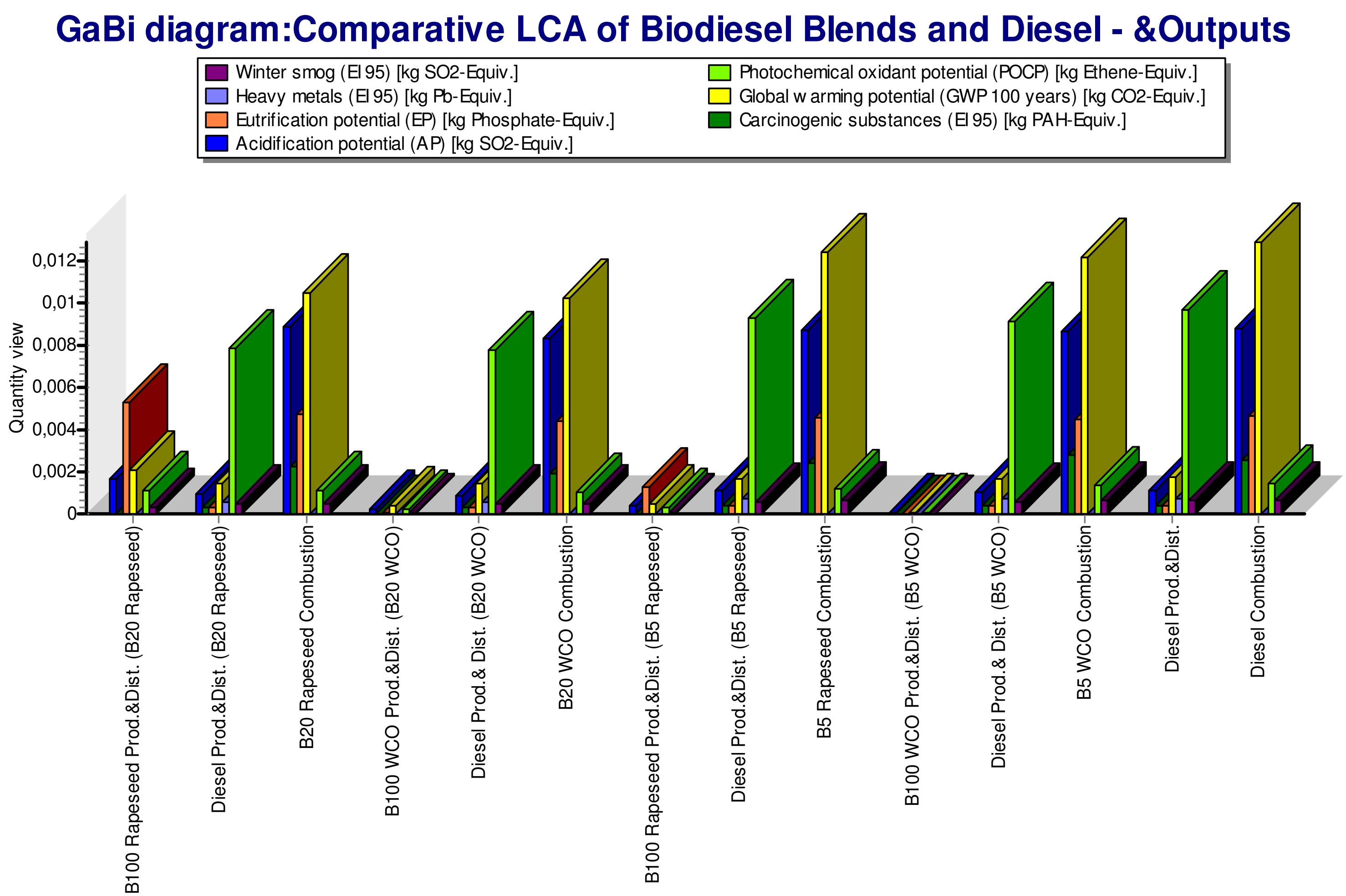

Figure 5.3 : Normalized impact potentials of fuels according to Ecoindicator95 (detailed graph).

5.3 Weighting

The evaluation of different normalized impact potentials is the basis of weighting. Relative importance of impact potentials has variations depending on local conditions. It does not mean that equal normalized impact potentials have equal importance in every condition. Environmental policies and country profiles need different weighting factors to evaluate the importance of the problems. Scores obtained in normalization step are weighted according to the importance of the problem and then, scores are added up to obtain the total environmental impacts.

There are several methods available for weighting. GaBi4 has weighting database including Ecoindicator95, Ecoindicator99, CML2001 and policy targets of different countries. By this way, it is possible to evaluate our scores with different weighting factors. However, soundness of the outcome is an important aspect of weighting so, the weighting factors of Ecoindicator95 are chosen as in the normalization step. The scores obtained in the normalization step are calculated according to equation 2.4.

The calculated weights of biodiesel blends and conventional diesel are shown in Figures 5.4, 5.5, E.1 and E.2. Related results are given in the Tables F.1-F.4. Global warming potentials of all biodiesel blends are less than the conventional diesel. It depends on the zero fossil carbon dioxide emissions of biodiesels. Acidification potentials of rapeseed biodiesel blends are clearly more than the diesel because of the cultivation applications. Due to environmental burdens of the rapeseed cultivation, rapeseed biodiesel blends have significant eutrophication potential, too. Except B5 WCO, all the biodiesel blends have positive performance on the carcinogenic substances. This result is related with the negative environmental performance of B5 WCO in the combustion stage [55]. Biodiesel is also good alternative to decrease heavy metal potentials according to the diesel production. Photochemical oxidant formation potentials of biodiesel blends are less than the conventional diesel. Although winter smog potential of WCO biodiesel blends are less than diesel, rapeseed biodiesel blends are negative performance on winter smog potential because of the rapeseed cultivation stage.

According to the weighting results, rapeseed production stage including cultivation and harvesting is determined as the most important stage of rapeseed biodiesel life cycle. It dramatically influences the overall performance of rapeseed biodiesel life cycle. This stage includes most of the acidification, eutrophication and winter smog potentials. Environmental efficiency of this stage is the main factor that affects the environmental performance of the rapeseed biodiesel. WCO biodiesel shows positive performance according to diesel because of having less application stages in its life cycle. However, it is determined that WCO collecting stage has a significant effect on the environmental performance of WCO biodiesel.

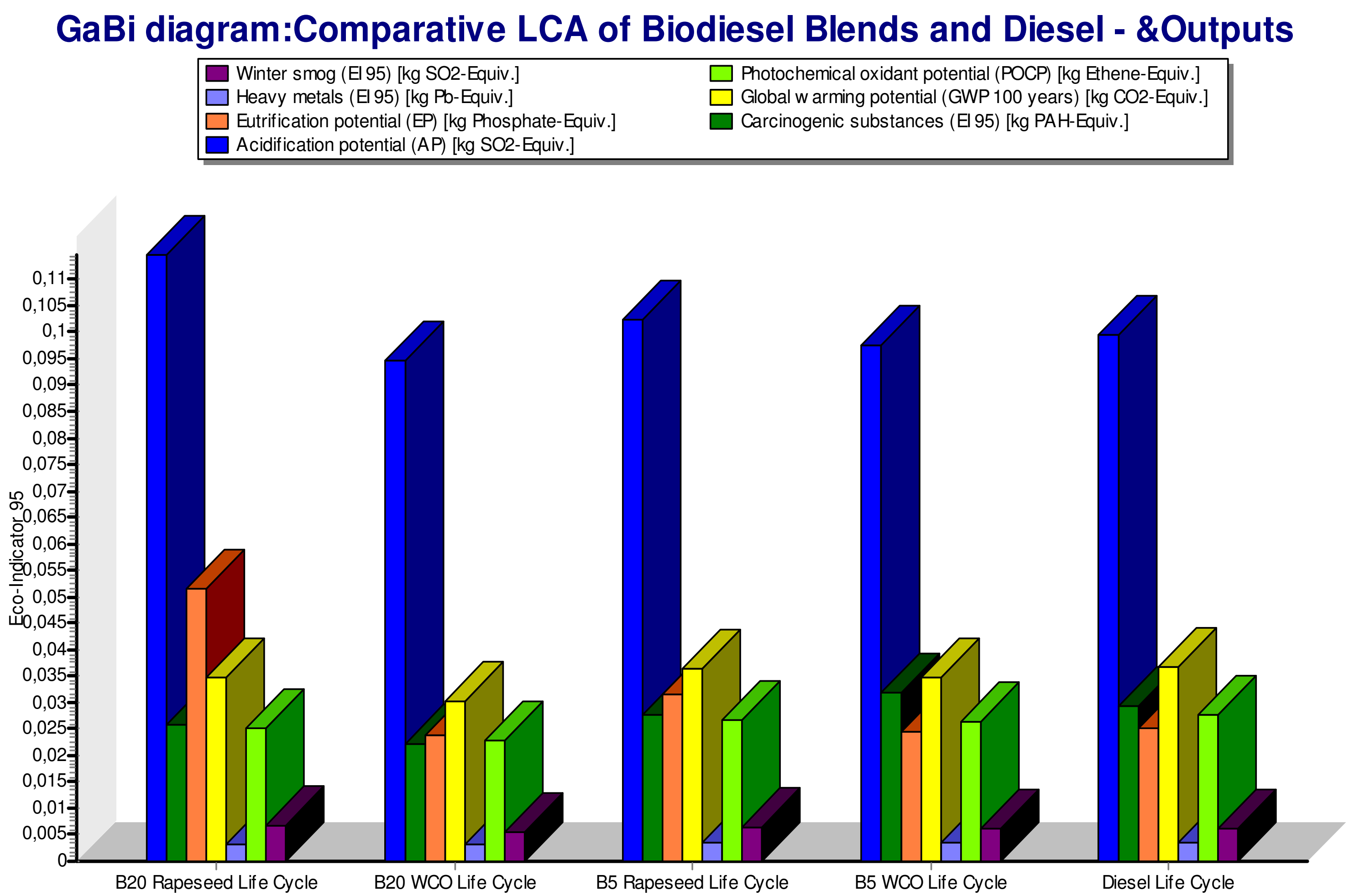

Figure 5.4 : Weighted impact potentials of fuels according to Ecoindicator95

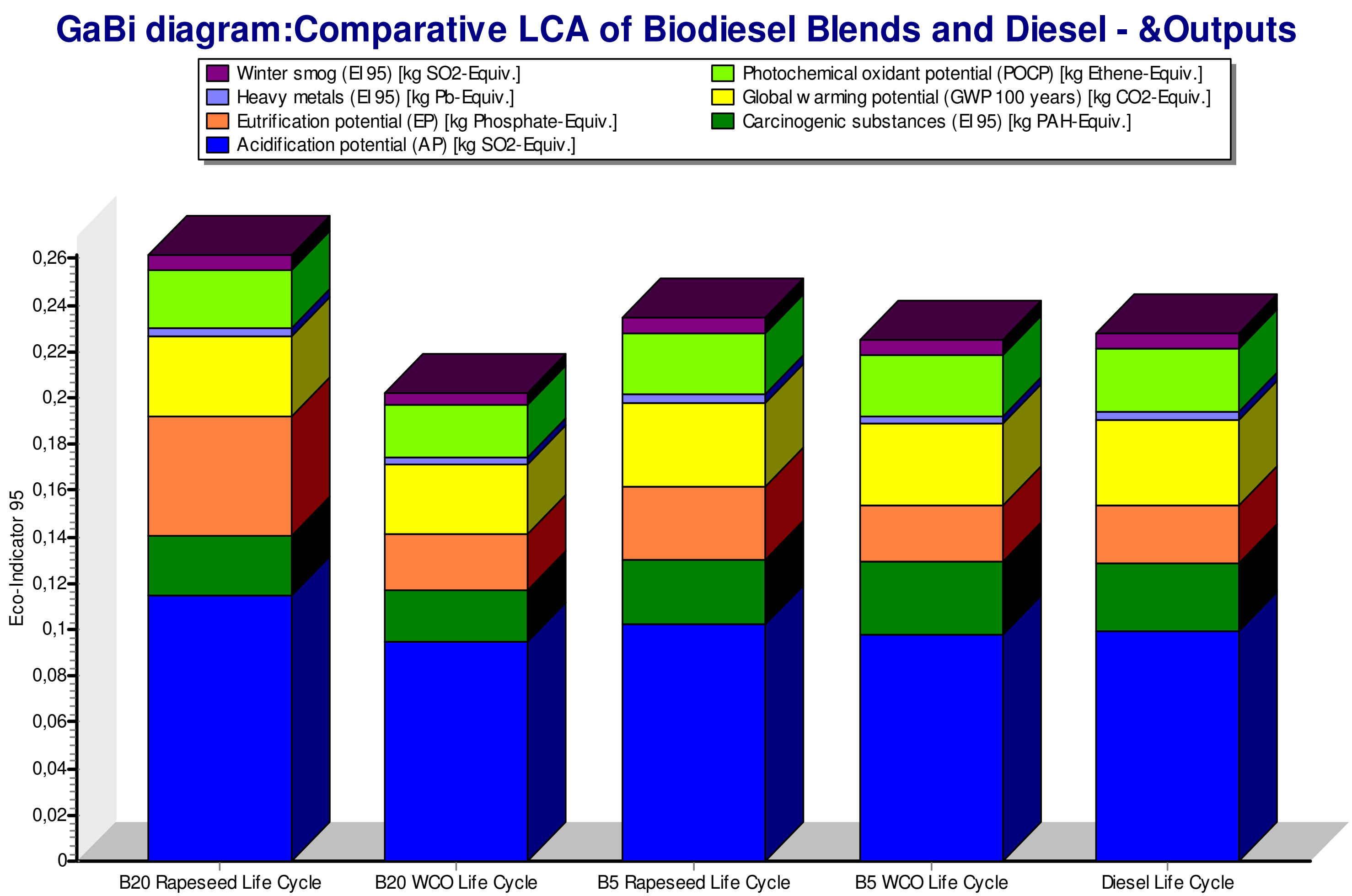

Figure 5.5 : Weighted impact potentials of fuels according to Ecoindicator95 (stacked graph)

6. CONCLUSION AND RECOMMENDATIONS

Biodiesel blends from different feedstocks and diesel are compared within the scope of the study. Ecoindicator95 is chosen as an evaluation method for the normalization and weighting steps. Scenario includes two different feedstocks to produce biodiesel. One of them is rapeseed oil and other is the waste cooking oil. The impact assessment is carried out for seven main environmental impacts. Although, it is possible to expand to the analysis with additional impacts, it may cause deviation from the real situation due to uncountable emissions depending on the database. Further studies are needed at this point. Additionally, it must be specified that LCA is dynamic process. Increasing accessibility to the real process data and obtaining detailed information on emissions can change the study's results during the time. However, study has the meaningful results in the present situation.

Rapeseed biodiesel and WCO biodiesel blends are both found to be good alternatives for limiting the carbon dioxide emissions. Decreases are observed for global warming potentials of biodiesels. This is due to the biogenic CO_2 content of the biodiesel blends. However, rapeseed production stage of rapeseed biodiesel is observed to significantly change the overall positive environmental effect of the rapeseed biodiesel. Environmental burdens arising from the cultivation and harvesting of rapeseed cause adverse impacts on acidification, eutrophication and winter smog potentials. When these impacts are evaluated in the weighting part of the study, the results indicate that the overall environmental performance of rapeseed biodiesel is worse than the conventional diesel.

WCO biodiesel blends show a superior performance compared to the diesel and rapeseed biodiesel blends. They are a good alternative for limiting the CO_2 emissions. Moreover, unlike rapeseed biodiesels, they do not have the negative environmental impacts due to the cultivation stage. It is also an environmentally friendly alternative way of waste elimination.

The results of the study determine that the biodiesel produced from waste cooking oils is the first priority of Turkey in alternative biofuel production. Although rapeseed biodiesel has a positive impact on limiting carbon dioxide emissions which cause the global warming, it is not a good alternative to the diesel if all the other environmental impacts are considered. WCO biodiesel production is determined as a sustainable way of biofuel production.

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REFERENCES

[1] **European Environment Agency (EEA)**, 2006. Transport and environment: facing a dilemma, *Term 2005: indicators tracking transport and environment in the European Union*, *Technical Report,* 3/2006, Copenhagen, Denmark.

[2] **European Environment Agency (EEA)**, 2008. Climate for a transport change, *Term 2007: indicators tracking transport and environment in the European Union*, *Technical Report,* 1/2008, Copenhagen, Denmark.

[3] **Hamelink, C.N.,** 2004. Outlook for advanced biofuels, *PhD Thesis*, University of Utrecht, Netherlands.

[4] **Commission of the European Communities,** 2006. Communication from the Commission, An EU Strategy for Biofuels, SEC(2006) 142, Brussels.

[5] **Oil Consumption of Turkey** <http://www.bp.com>, accessed at 06.11.2008.

[6] **International Energy Agency (IEA)**, 2004. *Biofuels for transport*, pp. 11-145.

[7] **Jensen, K.H. and Thyø, K.A.,** 2007. 2nd generation bioethanol for transport: the IBUS concept, *Master thesis*, Department of Manufacturing Engineering and Management, Technical University of Denmark.

[8] **Beer, T., Campbell, P.K. and Grant, T.,** 2007. The greenhouse and air quality emissions of biodiesel blends in Australia, *Australian Commonwealth Scientific and Research Organization (CSIRO) Report for Caltex Australia Ltd.*, KS54C/1/F2.29, Australia.

[9] **Elsayed M.A. and Mortimer N.D.,** 2006. North East biofuel supply chain carbon intenstiy assessment, *North Energy Associates Ltd. Report,* Sheffield, United Kingdom.

[10] **Camobreco, V., Duffield, J., Graboski, M., Shapouri, M. and Sheehan, J.,** 1998. Life cycle inventory of biodiesel and petroleum diesel for use in an urban bus, *National Renewable Energy Laboratory (NREL) Report for U.S.A. Department of Energy's Office of Fuels Development and U.S.A. Department of Agriculture's Office of Energy*, **NREL/SR-580-24089,** USA.

[11] **Chan, A., Fu, G. and Rollefson J.,** 2004. Assessment of the environmental performance and sustainability of biodiesel in Canada, *National Research Council Canada Report for Ontario Ministry of Agriculture and Food, Agriculture and Agri-Food Canada, Environment Canada, Industry Canada, Natural Resources Canada*.

[12] **Thyø K.A, Wenzel H.,** 2007. Life cycle assessment of biogas from maize silage and from manure, *2nd. draft*, Institute for Product Development, Technical University of Denmark.

[13] **Anyon, P., Beer, T., Edwards, J., Grant, T., Lapszewicz, J., Morgan, G., Nelson, P., Watson, H., and Williams, D.,** 2001. Comparison of transport fuels: The Stage 2 study of Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles, *Australian Greenhouse Office Technical Report,* **EV45A/2/F3C**, pp. 27-31, Australia.

[14] **Bomb., C., Deurwaarder, E., Kaberger, T. and McCormick, K.,** 2007. Biofuels for transport in Europe: Lessons from Germany and the UK, *Energy Policy*, **35**, 2256–2267.

[15] **ALBIYOBIR,** 2005. National Fuel Biodiesel (Ulusal Yakıt Biyodizel), *Workshop on biodiesel production situation from vegetable oil and WCO/Tallow in Turkey (Türkiye'de bitkisel ve atık/hayvansal yağlardan biyodizel üretiminde durum saptanması),* TÜBİTAK, Ankara, 2 December.

[16] **Biodiesel in Turkey** < http://www.albiyobir.org.tr/trde_b.htm>, accessed at 14.12.2008.

[17] **Vegetable Oils an Fats Industrialists Association Turkish Statistics** <http://bysd.org.tr/index.php?area=1&p=static&page=istatistikler>, accessed at 21.12.2008.

[18] **Süzer, S.** 2008. Kanola tarımı, Trakya Tarımsal Araştırma Enstitüsü, EDİRNE <http://www.pankobirlik.com.tr/KANOLA_TARIMI.pdf>, accessed at 12.11.2008.

[19] **Tan, Ş.,** 2007. Kanola (kolza) tarımı, Tarımsal Araştırmalar Genel Müdürlüğü, Ege Tarımsal Araştırma Enstitüsü Müdürlüğü, *Çiftçi Broşürü*, **134,** 1-10, İzmir.

[20] **News at the Local Newspaper Uzunköprü Adalet,** Kanola Buğdayı Solladı**,** <http://www.uzunkopruadalet.com/detay.php?subaction=showfull&i=121420391>, accessed at 12.11.2008.

[21] **U.S.A Environmental Protection Agency (EPA),** 2006. Life cycle assessment: Principle and practice, *U.S.A. National Risk Management Research Laboratory (NRMRL) Technical Report*, **EPA/600/R-06/060,** Cincinnati, USA.

[22] **European Environment Agency (EEA),** 1997. Life cycle assessment, A guide to approaches, experiences and information sources, *Environmental Issues Series*, **6,** pp.9-12, 51-72, Copenhagen.

[23] **Bacovsky, D., Körbitz, W., Mittelbach, M. and Wörgetter, M.,** 2007. Biodiesel production: Technologies and European Providers; *Report for International Energy Agency (IEA)*, **T39-B6,** pp.9-19, Paris.

[24] **UNEP,** 1996. Life Cycle Assessment: What it is and How to do it, United Nations Publications, Paris.

[25] **Freire, F. and Malça, J.,** 2006. Renewability and life-cycle energy efficiency of bioethanol and bio-ethyl tertiary butyl ether (bioETBE): Assessing the implications of allocation, *Energy*, **31**, 3362–3380.

[26] **Hauschild, M. and Wenzel, H.,** 2000. Life Cycle Assessment - *Environmental Assessment of Products*, pp. 155-189, CRC Press LLC, Denmark.

[27] **Canals, L.M.,** 2003. Contributions to LCA methodology for agricultural systems, *PhD Thesis*, Univesitat Autonoma de Barcelona, Spain.

[28] **Finvedden, G.,** 1999. A critical review of operational valuation/weighting methods for life cycle assessment, *Swedish Environmental Protection Agency Report*, **AFR-REPORT 253**, Stockholm.

[29] **Emmenegger, M.F., Frischknecht, R., Jungbluth, N. and Tuchschmid, M.,** 2007. Renewable fuels for advanced powertrains, Life cycle assessment of BTL-fuel production: Goal and Scope Definition, *ESU Services Ltd. Report for Swiss Federal Office for Education and Science, Swiss Federal Office of Energy*, pp.2-5, Switzerland.

[30] **USA Environmental Protection Agency (EPA)**, 2000. Framework for Responsible Environmental Decisionmaking (FRED): Using life cycle assessment to evaluate preferability of products, **EPA/600/R-00/095**, Cincinati, USA.

[31] **Effting, S., Goedkoop, M. and Oele, M.,** 2004. SimaPro7 database manual, Methods library, pp.5-13, Netherlands.

[32] **Use of Life Cycle Emissions Model (LCEM) in LCA** <http://www.ecotravel.org.uk/documents/LCA_of_alternative_fuels/Chap ter6.pdf>, accessed at 06.10.2008.

[33] **Goedkop, M.,** 1995. Eco-Indicator95 Final Report, *National Reuse of Waste Research Programme (NOH) Report*, **9523**, Utrecht.

[34] **Collignon, M., Demmers, M. and Goedkop, M.,** 1996. Eco-Indicator95 manual for designers, *National Reuse of Waste Research Programme (NOH) Report*, *Updated version,* **9524**, Utrecht.

[35] **The Ecoindicator95** <http://www.pre.nl/eco-indicator95/eco-indicator95.htm>, accessed at 06.10.2008.

[36] **Applications of LCA** <http://lca.jrc.ec.europa.eu/lcainfohub/applications.vm>, accessed at 07.11.2008.

[37] **Private Sector Applications of LCA** <http://www.dk-teknik.dk/lcaguide/kap22.htm>, accessed at 06.10.2008.

[38] **Use of LCA** <http://www.lca-center.dk/cms/site.aspx?p=776>, accessed at 06.10.2008.

[39] **Norris, G.A**., 2000. Estimating the value of life cycle assessments, *1st International conference on life cycle management*, pp. 157-162 in Proceedings, Copenhagen, Denmark, 26-29 August.

[40] **GaBi4 Manual**, 2003. Institute for Polymer Testing and Polymer Science (IKP) of the University of Stuttgart, PE Europe GMBH, Germany.

[41] **Dunmade, I.,** 2007. LCA software tools and approaches, *Annual General Meeting and Conference on Life Cycle Assessment in Environmental Practice*, Calgary, Canada, 25 April.

[42] **European Environment Agency (EEA)**, 2008. Success stories within the road transport sector on reducing greenhouse gas emission and producing ancillary benefits, *Technical Report*, 2, p.10, Copenhagen.

[43] **Birky, A., Greene, D., Gross, T., Hamilton, D., Heitner, K., Johnson, L., Maples, J., Moore, J., Patterson, P., Plotkin, S. and Stodolsky, F.,** 2001. Future U.S. Highway Energy Use: A Fifty Year Perspective, *Draft Technical Report for Office of Transportation Technologies Energy Efficiency and Renewable Energy, U.S Department of Energy,* pp. 10-11, USA.

[44] **European Environment Agency (EEA) Aggregated and Gap Filled Air Emission Data,** 2008. <http://dataservice.eea.europa.eu/download.asp?id=19432&filetype=.zip>, accessed at 09.11.2008.

[45] **European Environment Agency (EEA) ,** 2007. Greenhouse gas emission trends and projections in Europe 2007, *Tracking progress towards Kyoto targets*, 5, p.100, Denmark.

[46] **Foglia, T., Haas, M.J., McAloon, A.J. and Yee, W.C.,** 2006. A process model to estimate biodiesel production costs, *Bioresource Technology,* **97**, 671–678.

[47] **Friedrich, S.,** 2004. World wide review of the commercial production of biodiesel, A technological, economic and ecological investigation based on case studies, Institut für Technologie und nachhaltiges Produktmanagement der Wirtschaftsuniversität, Wien, Austria.

[48] **Booth, E., Booth, J., Cook, P., Ferguson, B. and Walker, K.,** 2005. Economic evaluation of biodiesel production from oilseed rape grown in North and East Scotland, Scottish Agriculture College (SAC), Scotland.

[49] **Prairie Research Associates (PRA) Inc.,** 2004. Biodiesel and other chemicals from vegetable oils and animal fats, *Technical Report for Agriculture and Agri-Food Canada*, p.14, Canada.

[50] **Aracil, J., Martinez, M. and Vicente G.,** 2004**.** Integrated biodiesel production: a comparison of different homogeneous catalyst systems, *Bioresource Technology*, **92**, 297–305.

[51] **Kleber, M.,** 2003. Lurgi Biodiesel Technology, *Mississippi Renewable Energy Conference,* Mississippi, USA*,* 25-26 March.

[52] **Clements, D., Gerpen, J.V., Pruszko, R. and Shanks, B.,** 2004. Biodiesel production technology, *National Renewable Energy Laboratory Report,* **NREL/SR-510-36244,** USA.

[53] **Gerpen, J.V., Knothe G. and Krahl J.,** 2005. The biodiesel handbook, pp. 27-39, AOCS Press, Champaign, USA.

[54] **Zadra, R.,** 2006. Improving process efficiency by the usage of alcoholates in the biodiesel production, *V. Fórum Brasil-Alemanha sobre Biodiesel*, Araçatuba, Brazil, 16 May.

[55] **Biobus Project**; 2003. Biobus Project Final Report, Biodiesel Demonstration and Assessment with the Société de transport de Montréal (STM), Canada.

[56] **Hustrulid, T. and Peterson, C. L.,** 1998. Carbon cycle for rapeseed oil biodiesel fuels, *Biomass and Bioenergy,* **14, 2,** 91-101.

[57] **EMRA Licensed Companies for Biodiesel Production in Turkey** <http://www.epdk.org.tr/lisans/petrol/bayilik/isleme.asp>, accessed at 14.12.2008.

[58] **USA Environmental Protection Agency (EPA);** 2002. A Comprehensive analysis of biodiesel impacts on exhaust emissions, *Draft Technical Report*, **EPA420-P-02-001**, USA.

[59] **Borg M. and Widman J**., 2001. Allocation of environmental loads, LCA in the building industry, **KTH BYMA IR 1998:2**, Sweden.

[60] **Lill, M. and Talve S.,** 2005. Introduction and implementation of life cycle assessment methodology in Estonia: Effects of Oil Shale Electricity on the Environmental Performance of Products (OSELCA); *OSELCA Task5: Life Cycle Assessment of An Energy Intensive Product, LIFE-Environment Demonstration Project,* pp.1-7, Estonia.

[61] **Enerji ve Çevre Dergisi (Energy and Environment Magazine),** 2008. Teknik Yayıncılık A.Ş., July-August, p.8

[62] **Kahramanmaraş Sütçü İmam Üniversitesi Çiftçi Köşesi Kanola Hakkında Bilgi** <http://ciftci.ksu.edu.tr/dokumanlar/kanola.html>, accessed at 12.11.2008.

[63] **Kaya, Z., Kırıcı, S., Özgüven, M., Tansı, S. and Yılmaz, M.A.,** 1999. Sigara fabrikası tütün atıklarının gübre olarak değerlendirilmesi, *Tr. J. of Agriculture and Forestry,* **23**, **1**, 43-51.

[64] **Lurgi AG Biodiesel Process Brochure** <http://www.lurgi.com/website/fileadmin/user_upload/1_PDF/1_Broshures_Flyer/englisch_neu_-_nov_2008/0301e_Biodiesel.pdf>, accessed at 06.11.2008.

[65] **Global Solutions 4 Pty Ltd,** 2002. Proposed establishment of a bio-diesel production facility, feasibility study for biodiesel production facility, *Report for A.J. Bush&Sons (Manufactures) Pty. Ltd.*, pp.37, 44, Queensland, Australia.

[66] **Bakhshi N.N., Dalai, A.K., Issariyakul, T. and Kulkarni, M.G.,** 2007. Production of biodiesel from waste fryer grease using mixed methanol/ethanol system; *Fuel Processing Technology*, **88**, **5**, 429-436.

[67] **Canakci., M.,** 2006. The potential of restaurant waste lipids as biodiesel feedstocks; *Bioresource Technology,* **98,** 183–190.

[68] **Canakcı, M. and Gerpen J.V.,** 2004. A pilot plant to produce biodiesel from high free fatty acid feedstocks, *Transactions of the ASAE*, **46(4)**, 945–954.

[69] **August 2008 Bulletin of the Edirne Commodity Exchange** <http://www.etb.org.tr/aylik/agustos08.pdf>, accessed at 06.10.2008.

[70] **Yıldız, M., 2008.** Private Communication with Mr. Müslim Yıldız, production manager of Bestaş Biodizel Enerji San. ve Tiç. A.Ş., at 27.10.2008

APPENDICES

Appendix A: Subplans for Rapeseed and WCO Biodiesel Life Cycles

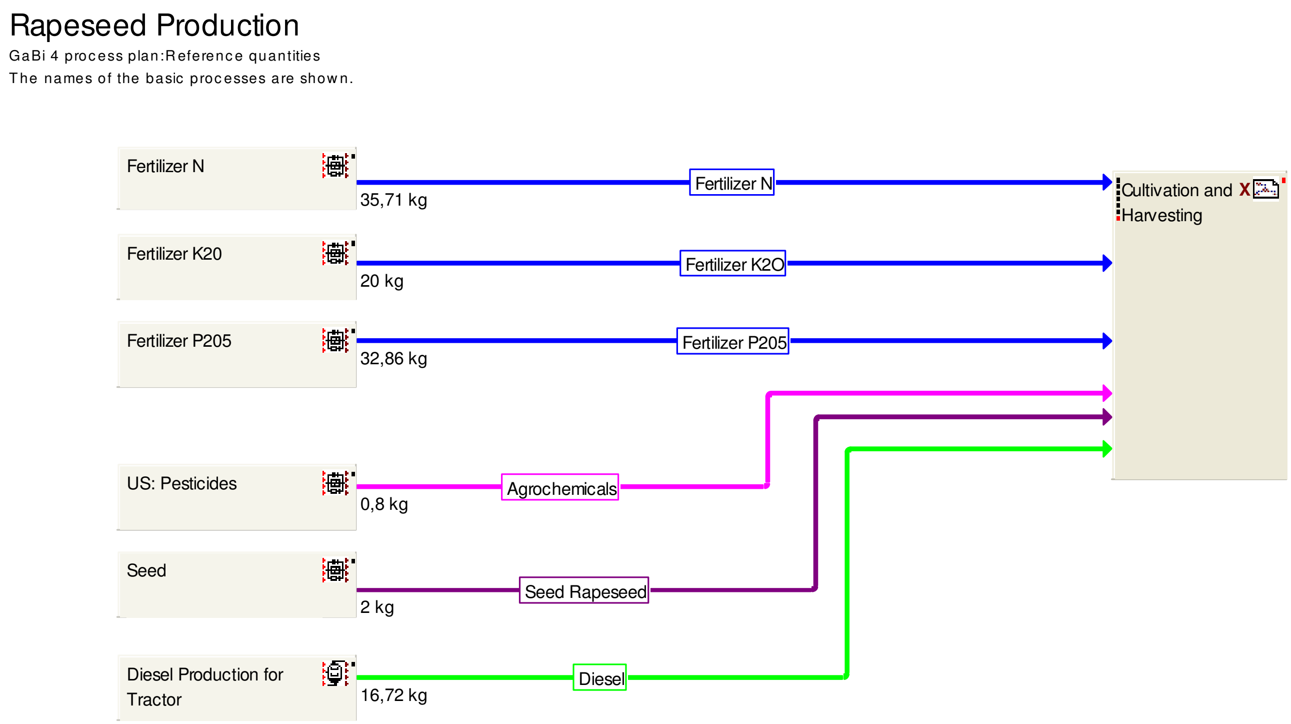

Figure A.1 : Rapeseed production

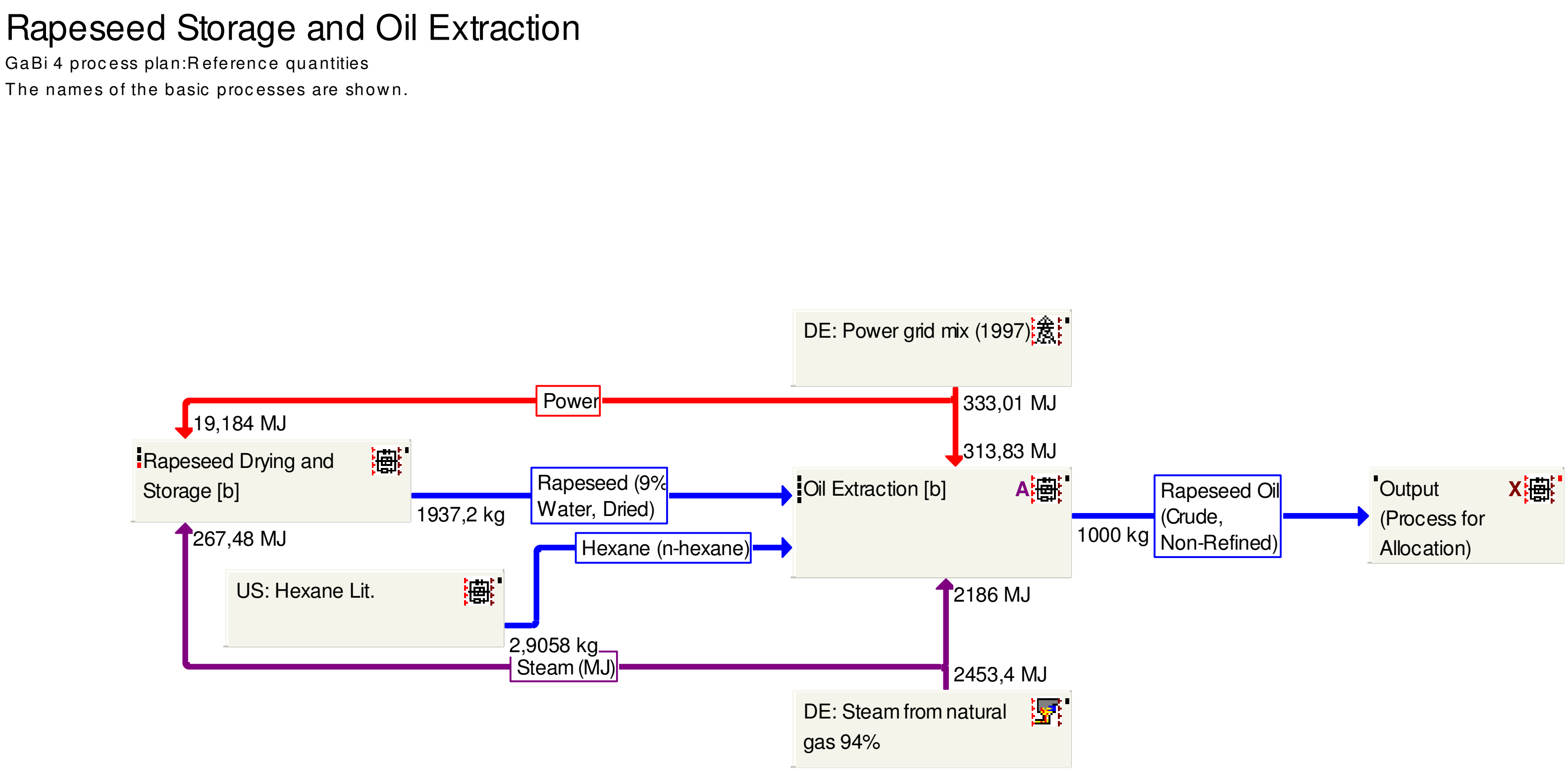

Figure A.2 : Rapeseed storage and oil extraction

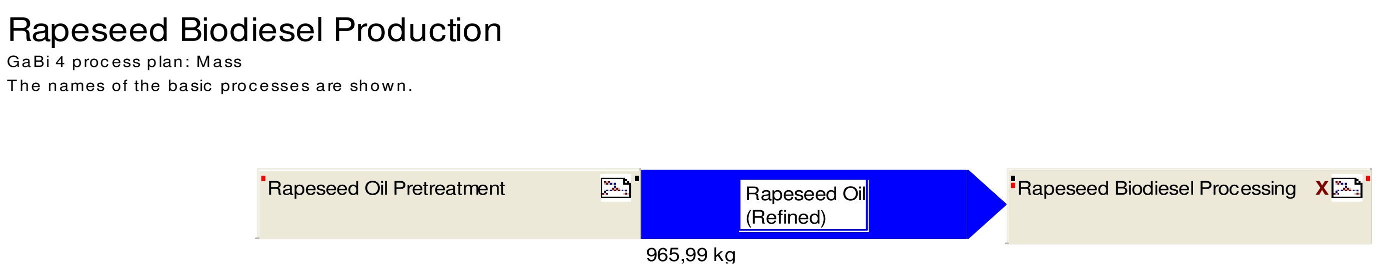

Figure A.3 : Rapeseed biodiesel production

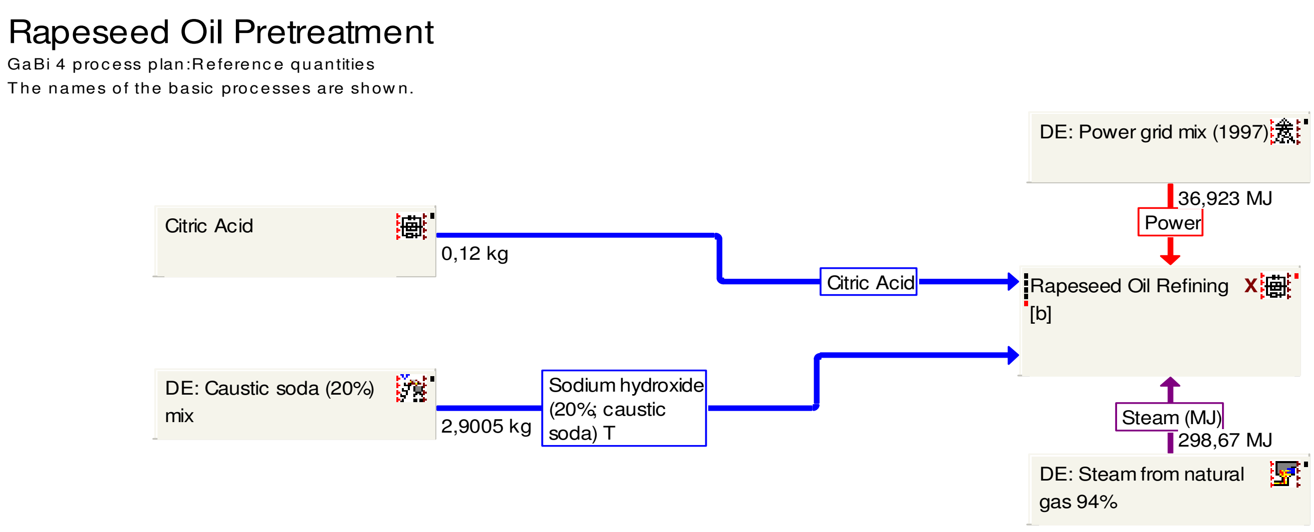

Figure A.4 : Rapeseed oil pretreatment (Subplan of rapeseed biodiesel production)

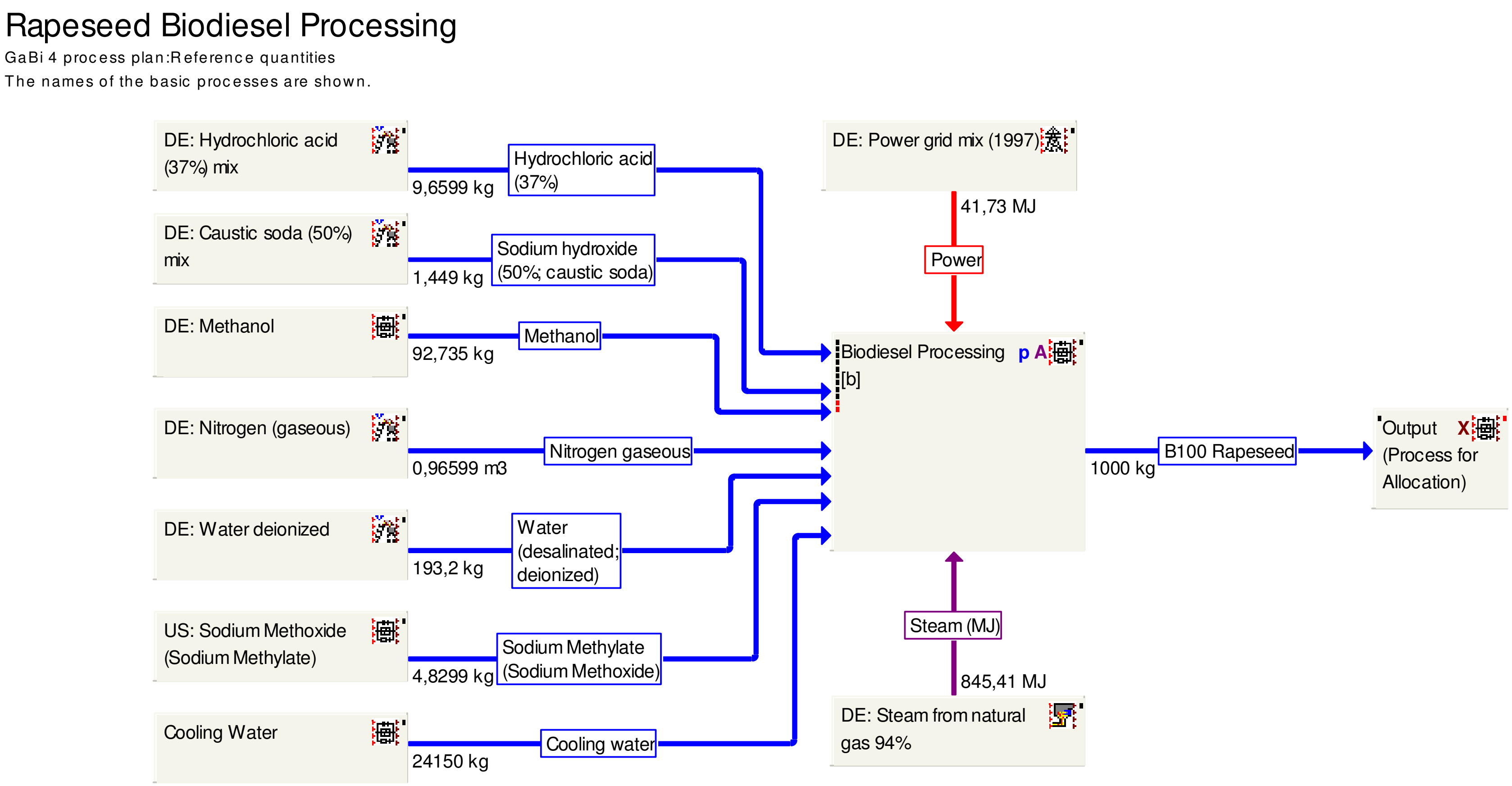

Figure A.5 : Rapeseed biodiesel processing (Subplan of rapeseed biodiesel production)

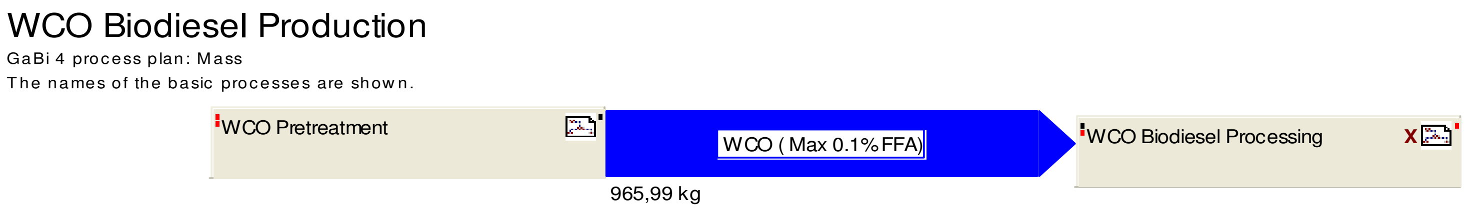

Figure A.6 : WCO biodiesel production

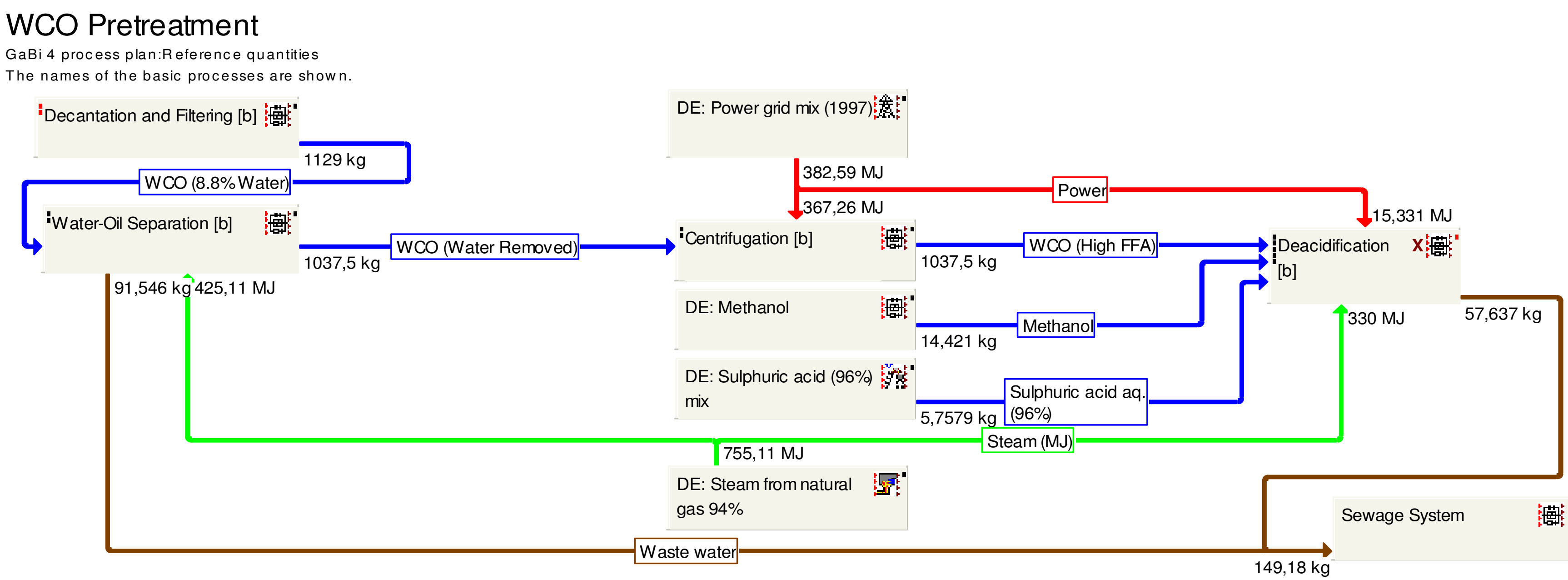

Figure A.7 : WCO pretreatment (Subplan of WCO biodiesel production)

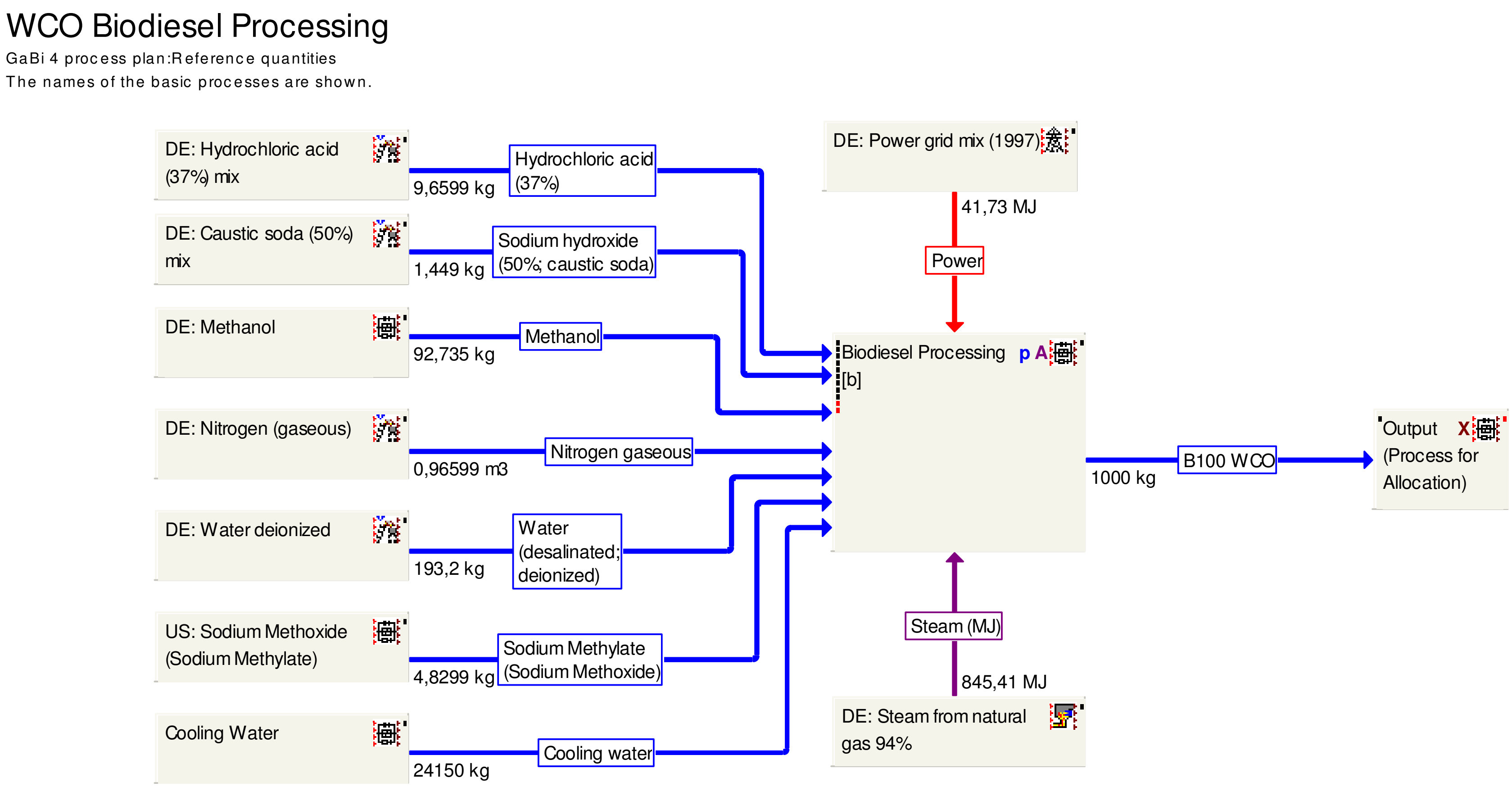

Figure A.8 : WCO biodiesel processing (Subplan of WCO biodiesel production)

Appendix B: Inventory Data for Fuel Life Cycles

Table B.1: Inventory data for rapeseed production.

	Unit	Amount Per 1000 kg Rapeseed[a]	Source	Process database
Inputs				
Pesticides	kg	0,8	Reference[b]	Reference[c]
Fertilizer N	kg	35,7	Reference[d]	SimaPro7
Fertilizer P_2O_5	kg	32,9	Reference[d]	SimaPro7
Fertilizer K_2O	kg	20	Reference[d]	SimaPro7
Seed	kg	2	Reference[e]	Reference[f]
Diesel	kg	16,7	Reference[g]	GaBi4
Outputs				
Agricultural emissions				SimaPro7
Diesel emissions				GaBi4
Straw	kg	975	Reference[b]	

a. Turkish literature has different amounts for rapeseed yield. It is accepted that rapeseed agriculture is performed in the northwestern area of the Turkey. The yield is accepted as 3500kg/ha according to the local news on harvesting. This yield also depends that modern agriculture methods are used at this part of Turkey. Water content is accepted 13% according to the evaluated literature, current news and considering the developments in the agricultural industry[9,18-20,62].

b. Reference [9].

c. Reference [10]: The pesticides production data is prepared according to LCA study on Soybean Biodiesel in US. This data includes the all resource consumption and emissions of the agricultural chemicals used in soybean agriculture. Due to lack similar data for rapeseed agriculture, this data is used for the study.

d. There are many differences for fertilizer applications in the Turkish literature. It depends on the different characteristics of the lands. Due to this reason, application rates of fertilizers are estimated by evaluating different sources [18,19,62,63].

e. Reference [62].

f. Process is prepared according to data from Reference [9]. The reference only includes GHG emissions. It is accepted that this has no significant effect on the overall results of life cycles.

g. There is not any process for the tractor in GaBi4. Therefore, emissions of GaBi4 truck trailer process data with 15 tonnes total capacity and 9.3 tonnes payload is accepted for tractor emissions.

Table B.2: Inventory data for rapeseed drying.

	Unit	Amount Per 1000 kg Rapeseed[a]	Source	Process database
Inputs				
Rapeseed 13% water	kg	1046	Reference[a]	
Steam	Mj	9.9	Reference[a]	GaBi4
Power	Mj	138.1	Reference[a]	GaBi4
Outputs				

a. Reference [9].

Table B.3: Inventory data for rapeseed oil extraction.

	Unit	Amount Per 1000 kg Crude Rapeseed Oil	Source	Process database
Inputs				
Rapeseed 9% water	kg	2506	Reference[a]	
Hexane	kg	3.76	Reference[a]	Reference[b]
Steam	Mj	2828.1	Reference[a]	GaBi4
Power	Mj	406.0	Reference[a]	GaBi4
Outputs				
Rapeseed meal	kg	1499	Reference[a]	
Hexane (NMVOC to Air)	kg	3.76	Reference[a]	
Solid waste	kg	7.5	Reference[a]	

a. Reference [8].

b. Reference [10]: Hexane process data of biodiesel LCA which is performed in USA is used.

Table B.4: Inventory data for rapeseed oil pretreatment (refining).

	Unit	Amount Per 1000 kg Refined Rapeseed Oil	Source	Process database
Inputs				
Crude rapeseed oil	kg	1026	Reference[a]	
Citric acid	kg	0,12	Reference[b]	Reference[c]
Sodium hydroxide	kg	2,9	Reference[b]	GaBi4[d]
Steam	Mj	298.7	Reference[a]	GaBi4
Power	Mj	36.9	Reference[a]	GaBi4
Outputs				
Solid waste	kg	25.6	Reference[a]	

a. Reference [8].

b. Data from Reference [9] is adapted to the Reference [8]. These data include the oil extraction stage of LCA study carried out in UK [9].

c. Process is prepared according to data from Reference [9]. The reference only includes the GHG emissions. It is accepted that this has no significant effect on the overall results of life cycles.

d. GaBi4 process data includes 50% caustic soda. Due to this reason, new process is prepared according to caustic soda ratios.

Table B.5: Inventory data for rapeseed biodiesel and WCO biodiesel processing.

	Unit	Amount Per 1000 Kg Biodiesel	Source	Process database
Inputs				
Pretreated oil	kg	1000		
Sodium Methylate	kg	5	Reference[a]	Reference[b]
Hydrochloric Acid (37%)	kg	10	Reference[a]	GaBi4[c]
Sodium Hydroxide (50%)	kg	1.5	Reference[a]	GaBi4
Nitrogen	m^3	1	Reference[a]	GaBi4
Water	kg	200	Reference[a]	GaBi4
Cooling Water	m^3	25	Reference[a]	Reference[d]
Methanol	Kg	96	Reference[a]	Reference[e]
Steam	Mj	875.2	Reference[f]	GaBi4
Power	Mj	43.2	Reference[a]	GaBi4
Outputs				
Glycerine (80%, crude)	kg	125	Reference[a]	

a. Reference [64].

b. Reference [10]: Sodium methylate process data is prepared according to the LCA study in USA.

c. GaBi4 process data for 100% HCI acid is arranged for the 37% HCI.

d. There isn't any data for cooling water process. Due to this, cooling water process is prepared evaluating the power consumption of Energia Company's biodiesel process [65].

e. Process is prepared according to data from LCA study in Reference [12].

f. There isn't any data related with steam properties. LCA study in Canada uses the same process (Lurgi Gmbh) but amount of process steam (kg per tonne biodiesel) is different [11]. However, data used in the thesis comes from the Lurgi Gmbh's webpage so it is accepted as more reliable [64]. The steam characteristics (energy/per kg) given in Canada study is used at this stage. This approach is also acceptable, if it is compared with GaBi4 steam flows' properties.

Table B.6: Inventory data for WCO filtering and decantation[a]

	Unit	Amount Per 1000 kg WCO (7.5% water)	Source	Process database
Inputs				
WCO (15% solid, water)	kg	1081	Reference[a]	
Outputs				
Sludge	kg	81.1	Reference[a]	

a. Energy consumption of this stage is neglected. In the literature, there are many different data for solid and water ratio of the WCO [11,52,66,67]. Some of them are extremely high (up to 30% of WCO). This causes higher diesel consumption for WCO collecting. Increasing solid-water ratio causes increasing environmental burdens. However, more sustainable approach is carried out in the thesis. Water and solid ratio of WCO is accepted as 15%.

Table B.7: Inventory data for water-oil separation[a] of WCO.

	Unit	Amount Per 1000 kg WCO (water removed)	Source	Process database
Inputs				
WCO (8.8% water)	kg	1088.24	Reference[a]	
Steam	Mj	409.8	Reference[a]	GaBi4
Outputs				
Water (removed)	kg	88.24	Reference[a]	

a. Electrical energy consumption of this stage is neglected. Water content of WCO is 8.8%. This water content is removed by heating. Steam consumption is calculated according to reference [11].

Table B.8: Inventory data for WCO centrifugation (solid removal).

	Unit	Amount Per 1000 kg WCO	Source	Process database
Inputs				
WCO (water removed)	kg	1000	Reference[a]	
Power	Mj	354	Reference[a]	GaBi4
Outputs				

a. Reference [11]. Removed solid amount is neglected.

Table B.9: Inventory data for WCO deacidification.

	Unit	Amount Per 1000 kg WCO (max 0.1% FFA content)	Source	Database
Inputs				
WCO High FFA	kg	1038		
Sulphuric acid	kg	5,8	Reference[a]	GaBi4
Methanol	kg	14,4	Reference[a]	Reference[b]
Steam	Mj	330	Reference[c]	GaBi4
Power	Mj	15,3	Reference[d]	GaBi4
Outputs				
Waste water	kg	57.6	Reference[a]	

a. Reference [68].

b. Process is prepared according to data from LCA study in Reference [12].

c. There are limited data. Due to this, available information from Reference [11] is adapted to the study.

d. There are limited data. Due to this, available information from Reference [12] is adapted to the study.

Table B.10: Inventory data for the combustions of fuels[a]

Emissions	No.2 Diesel	B5 Rapeseed	B20 Rapeseed	B5 WCO	B20 WCO
	gr/Mj	gr/Mj	gr/Mj	gr/Mj	gr/Mj
Carbon Dioxide (Fossil)[b]	220,71	212,37	178,46	208,78	175,94
Carbon Monoxide (CO)	0,22905	0,19926	0,16462	0,20335	0,15717
Total Hydrocarbons[c]	0,06294	0,05140	0,04953	0,05922	0,04730
Total Particulate Matter	0,01496	0,01509	0,01247	0,01473	0,01288
PAH	0,000036	0,000034	0,000032	0,000040	0,000027
Sulphur Dioxide (SO_2)[d]	0,06421	0,06100	0,05137	0,06100	0,05137
Sulphate (SO_4)[e]	0,05004	0,04900	0,04145	0,05038	0,04265
Nitrogen Oxides (NO_x)	1,76834	1,75903	1,79777	1,73296	1,68827
BETX	mg/Mj	mg/Mj	mg/Mj	mg/Mj	mg/Mj
Benzene	0,492	0,384	0,397	0,504	0,397
Ethyl Benzene	0,186	0,107	0,054	0,136	0,107
Toluene	2,872	2,636	2,351	2,665	2,256
O-Xylene	0,070	0,107	0,149	0,095	0,136
Hydrocarbons	6,983	6,165	5,466	5,958	5,152
Ethylene	5,070	4,524	3,797	4,863	3,702
Acetylene	0,545	0,368	0,343	0,463	0,397
Carbonyls[f]	mg/Mj	mg/Mj	mg/Mj	mg/Mj	mg/Mj
Formaldehyde	8,660	7,973	7,636	7,933	5,985
Acetaldehyde	8,660	7,973	7,636	7,933	5,985
Acetone	1,443	1,063	1,018	1,058	0,798
Propionaldehyde[g]	1,443	1,063	1,018	1,058	0,798
Acrolein	1,443	1,063	1,018	1,058	0,798
(iso) butyraldehyde	1,443	1,063	1,018	1,058	0,798

a. Emission data in table are given per unit work produced (gr/Mj, mg/Mj). Data are taken from the Reference [55] except SO_2 data. SO_2 emission data is taken from Reference [10].

b. Fossil CO_2 amount of biodiesel blends are calculated according to the volumetric blend ratio of the biodiesel. Deviations from the real situation are negligible. B100 biodiesel is accepted as a fuel that has a zero CO_2 emission. However, in the former stages of this study, B100 biodiesel had been accepted as a fuel that has 1/19 fossil carbon in the total carbon content. This approach had depended on the LCA study of NREL [10]. In the NREL study fossil carbon content of the methyl bond is added to the final product B100. According to this study, biodiesel and glycerin co-products result from the reaction of methanol (non-biological origin) and the triglyceride of biological origin. If one were to tag the carbon atoms in the biodiesel methyl ester, there would be the one carbon in the final methyl group attached to the carboxyl group that would be of non-biological origin. As the length of the preponderant carbon chain to which the methyl group is attached is 18 carbon atoms, the ratio of organic carbon to the total carbon content in biodiesel is 18/19. However, we have accepted the application of LCA study in Canada, later. This perspective is to consider that as part of the total net balance of the reaction. The organic carbon content of the triglyceride exactly matches the carbon content of the biodiesel, and the inorganic content of the methanol exactly matches the carbon content of the glycerin co-product. This understanding leads to a simpler analysis where the organic origin of the glycerin's carbon need not enter into the analyses. This perspective is only meaningful if glycerine substitutes the fossil glycerine and our study accepts this approach [11].

c. Methane emissions are neglected. PAH, BETX and carbonyl emissions are subtracted from the total hydrocarbon emissions. Remaining amounts are accepted as non-methane volatile organic compounds.

d. Sulphur dioxide data of diesel is taken from Reference [10]. Emissions of biodiesel are calculated theoretically according to SO_2 emission of diesel fuel.

e. Sulphate emissions (SO_4) are neglected. GaBi4 version doesn't include the environmental burdens of SO_4.

f. There is limited information for the ratios of carbonyl emissions in total carbonyls. According to the Reference [55], total carbonyl emissions are distributed.

g. There is no emission data for the propionaldehyde in GaBi4. Propionaldehyde emissions are neglected.

Table B.11: Inventory data for the engine efficiencies of fuels[a,b]

Fuel	Consumption (lt/Mj)	Efficiency (%)
No.2 Diesel	0.08508	32.27
B5 Rapeseed	0.08587	31.90
B20 Rapeseed	0.08616	32.08
B5 WCO	0.08486	32.40
B20 WCO	0.08553	32.32

a. Data is taken from Reference [55]. There is a little mistake in the results of Reference [55] and it is corrected according to Reference [11].

b. In the table giving the thermodynamic and mechanical efficiencies in Biobus study, the conversion from brakehorsepower-hour to metric units was based on a conversion factor of 735.5W/bhp. This is associated with a so-called metric horsepower unit sometimes used. However, throughout the bulk of the report the correct conversion value of 746W/bhp was used. This means that the engine efficiency values given on the Biobus report, page 60 are in error of 0.4% [11].

Appendix C: Allocation Methodology

In general, a single production system produces more than one good, an approach is needed to proportion the environmental impacts of the production system to the different economic goods [8].

There are many alternatives for the allocation. The International LCA Standards have a hierarchy for the application of allocation approaches, and the preferred approach is to use consequential LCA. This is called as the "system boundary expansion". The other option is the attributional approach which is to allocate emissions and resource uses based on a common and relevant attribute of the two co-products. This may be economic value, mass, energy, volume, sugar content, protein content and so on [8]. Mass-based allocation and energy-based allocation need a special situation to use properly. Economic allocation represents the main driver behind production, and may be the only comparable attribute between the co-products. The two basic approaches are shown in Figure C.1 [8].

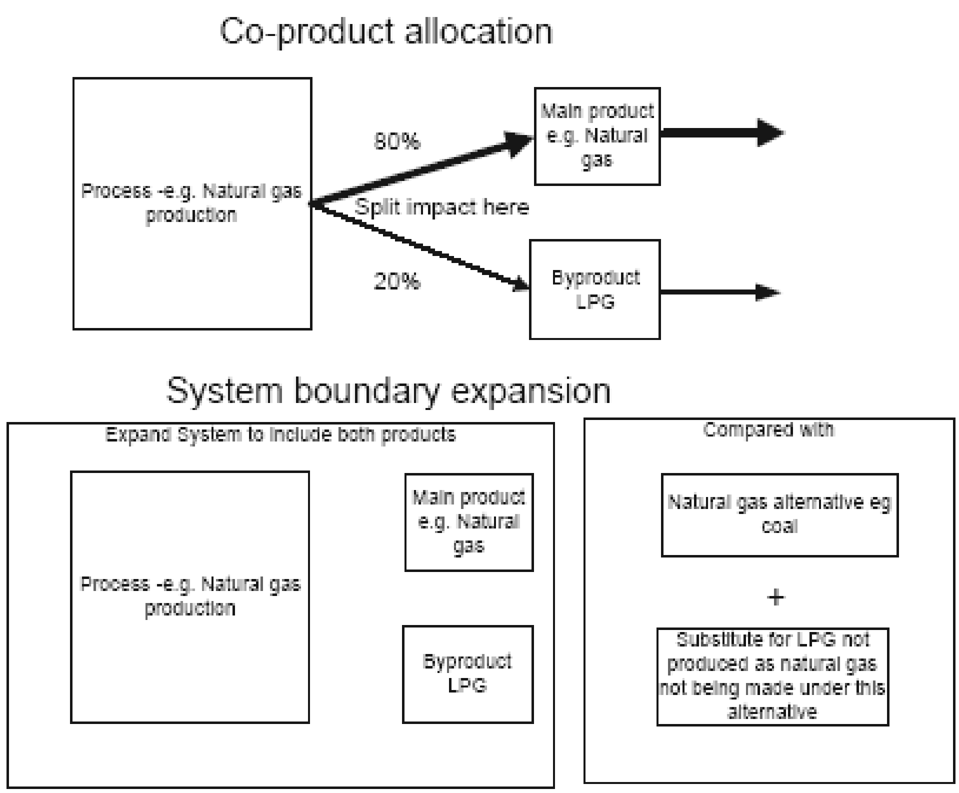

Figure C.1: Different allocation procedures [8].

An economic allocation is carried out within the scope of this thesis. Economical values of the products are entered to GaBi4 database. Allocation is performed by multiplying the amounts of products with economical values. Economical values of the products are obtained from the web and special interviews. Data are given below in Table C.1. As given in the table, market price of rapeseed oil is higher than the biodiesel at the present time. Feasible biodiesel production is impossible at this situation. Data is obtained in the chaotic market conditions, so it may have some deviations from the real situation. However, data source for rapeseed oil and rapeseed meal is same. Data source for biodiesel and glycerine is same, too. By this way, deviations are limited in the assessment, because environmental burdens of emissions are distributed according the allocation ratio of each stage, separately.

Table C.1: Economical values of the products for allocation.

Products and byproducts	Price YTL/Tonne	Source
Rapeseed oil	1686,3	Reference[a]
Rapeseed meal	330,5	Reference[a]
Biodiesel	1420	Reference[b]
Glycerine	400	Reference[b]

a. Commercial data from the web [69].

b. Private communication [70].

Appendix D: Characterization Graphs of Fuels

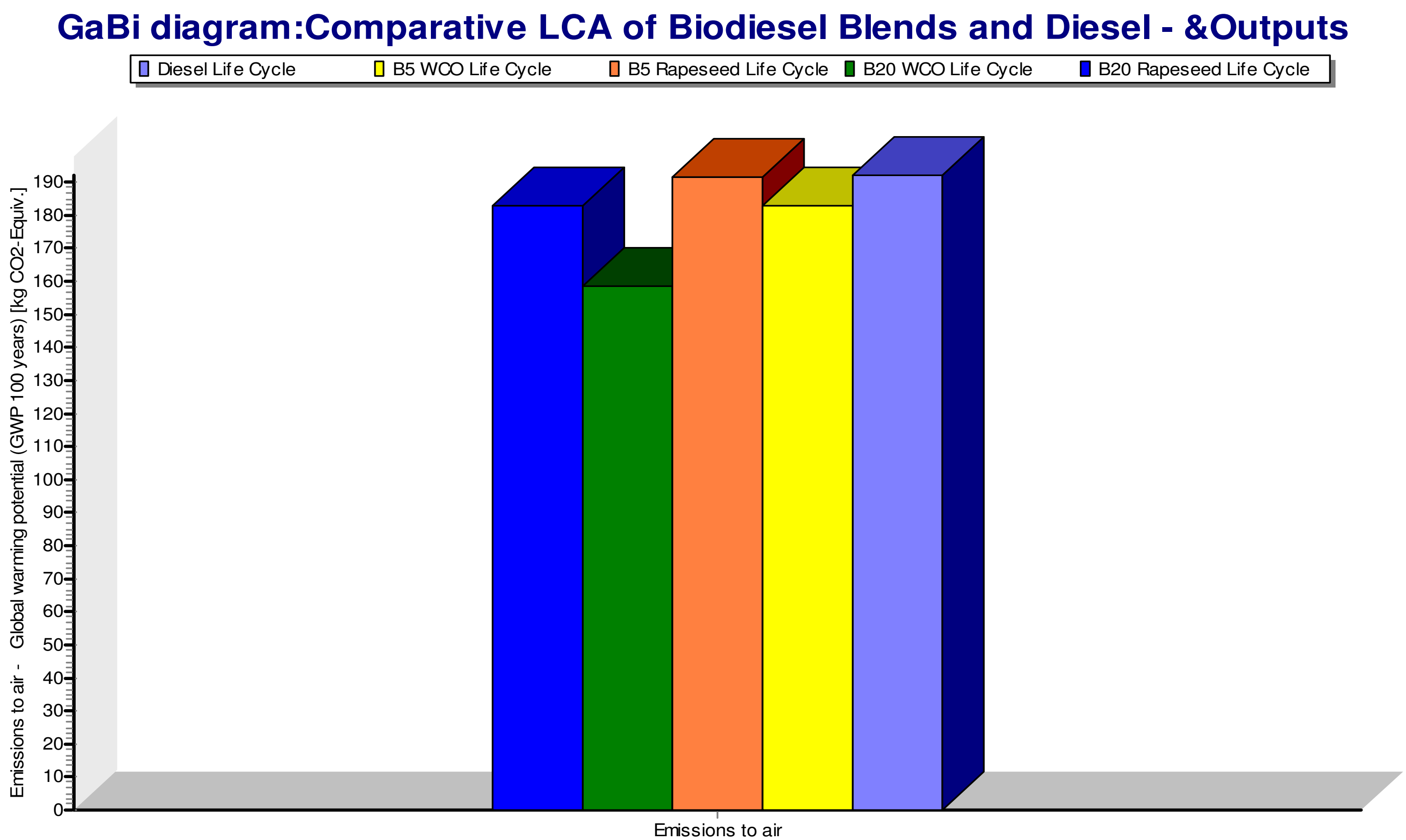

Figure D.1 : Global warming potentials of fuels

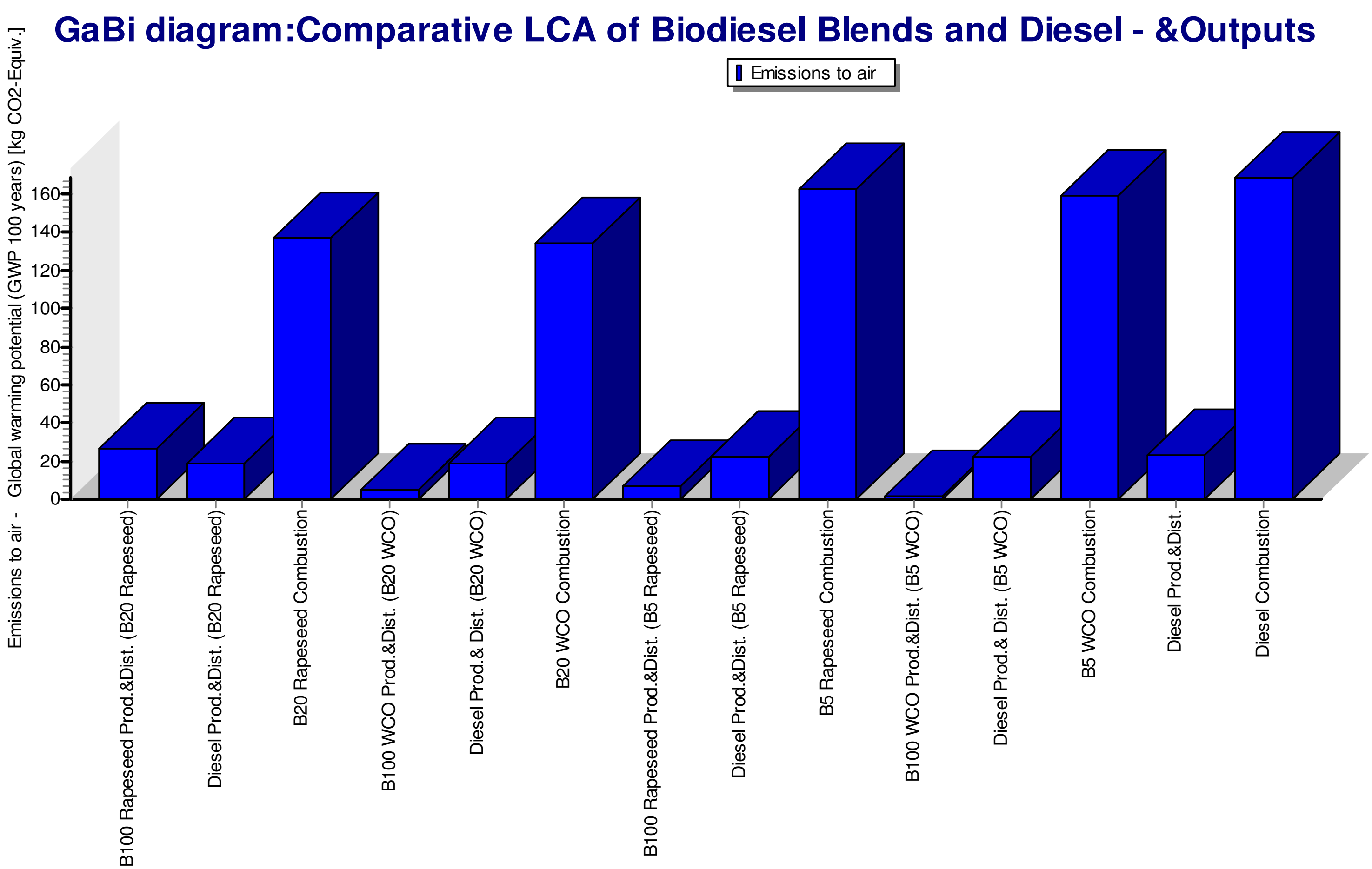

Figure D.2 : Global warming potentials of fuels (detailed view).

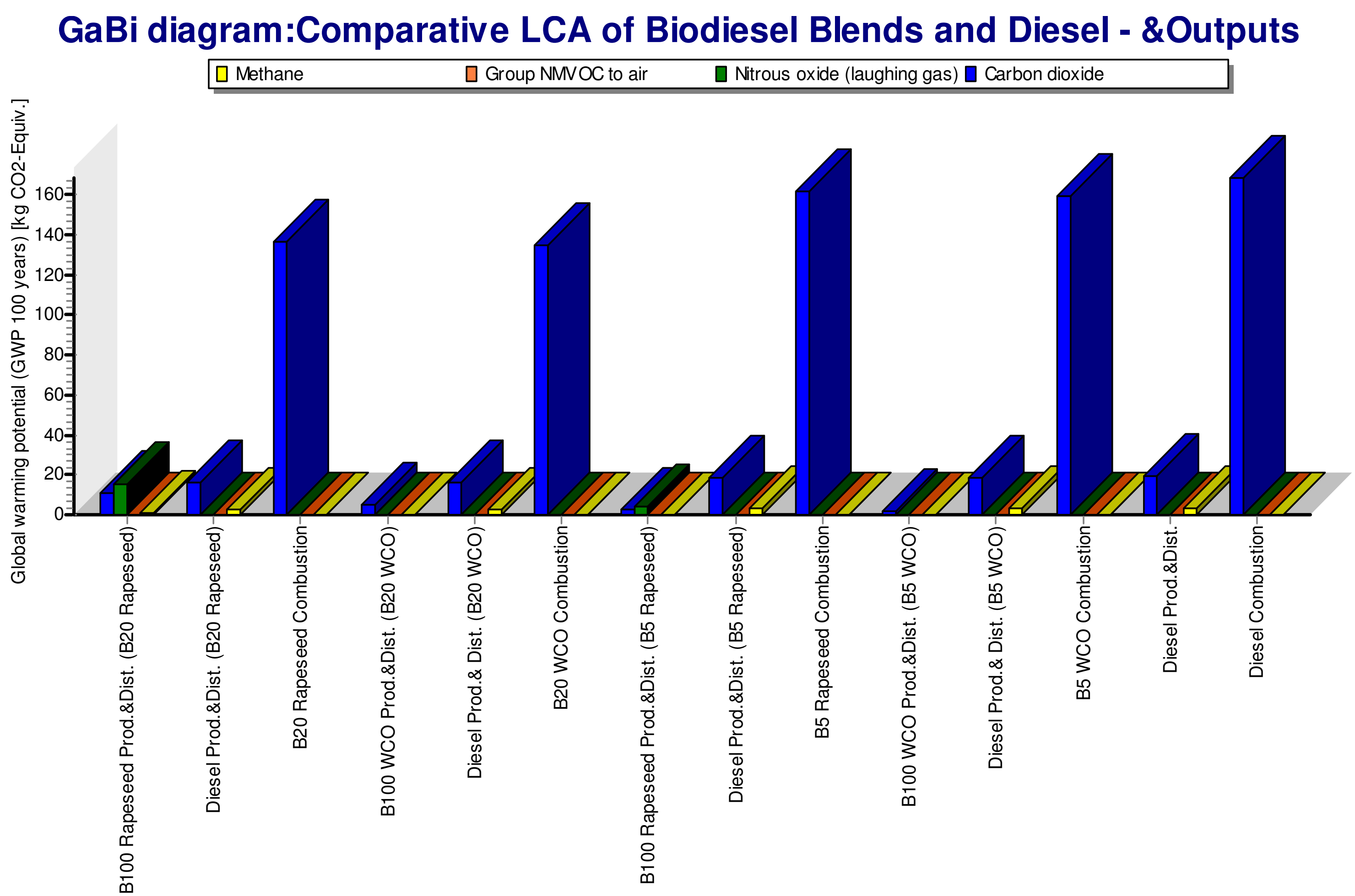

Figure D.3 : Global warming potentials of fuels (detailed view including emissions)

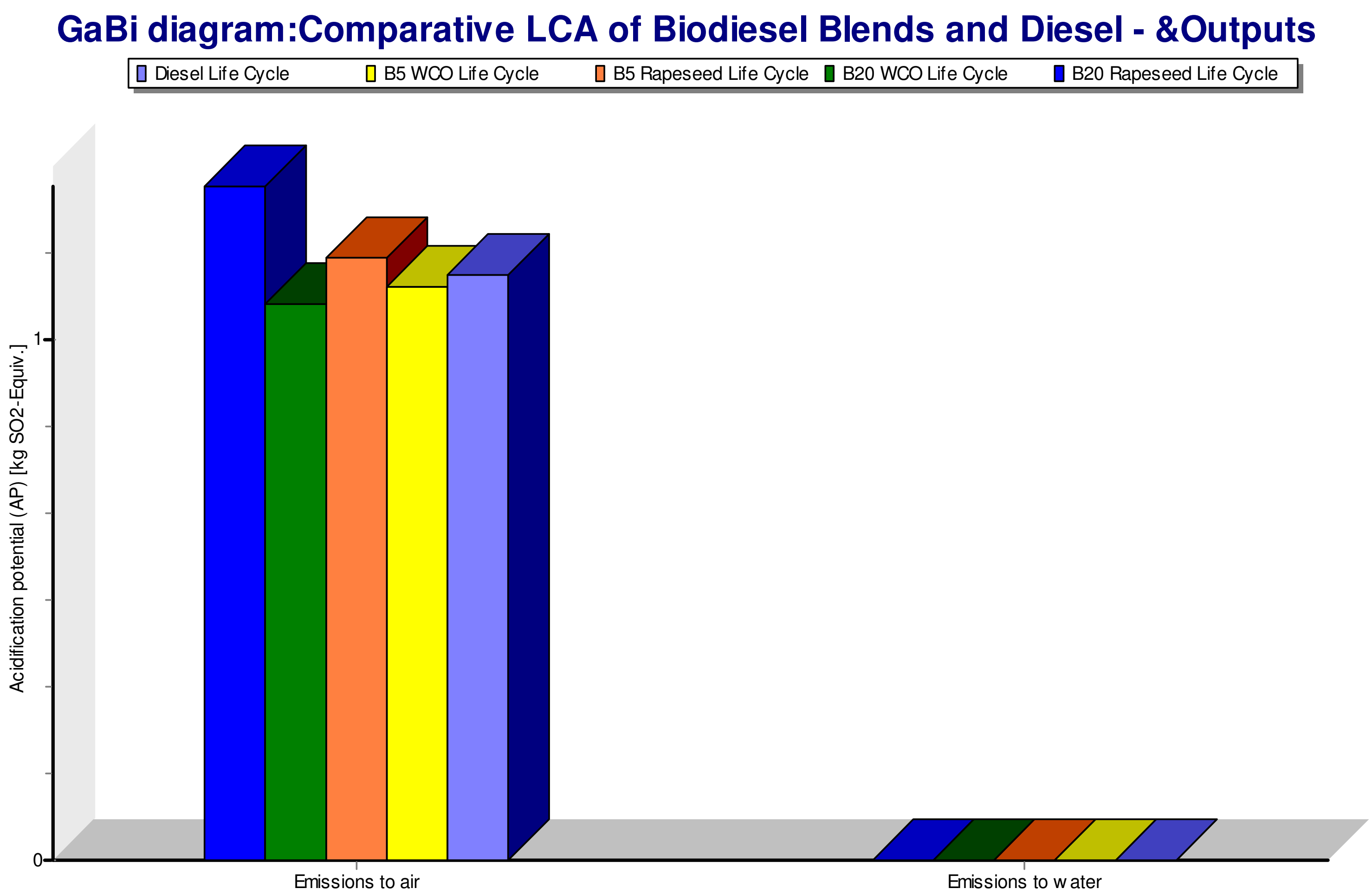

Figure D.4 : Acidification potentials of fuels.

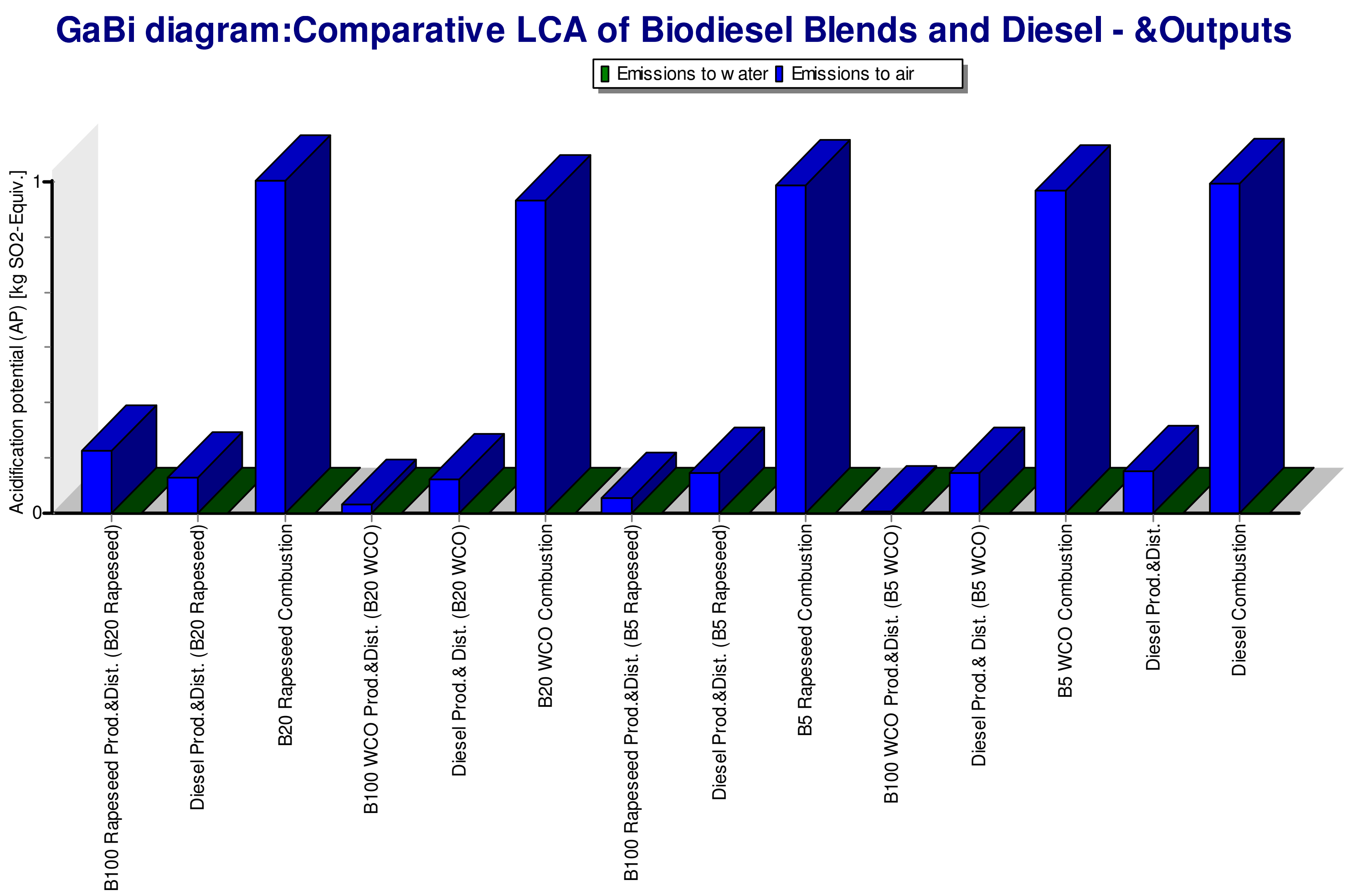

Figure D.5 : Acidification potentials of fuels (detailed view).

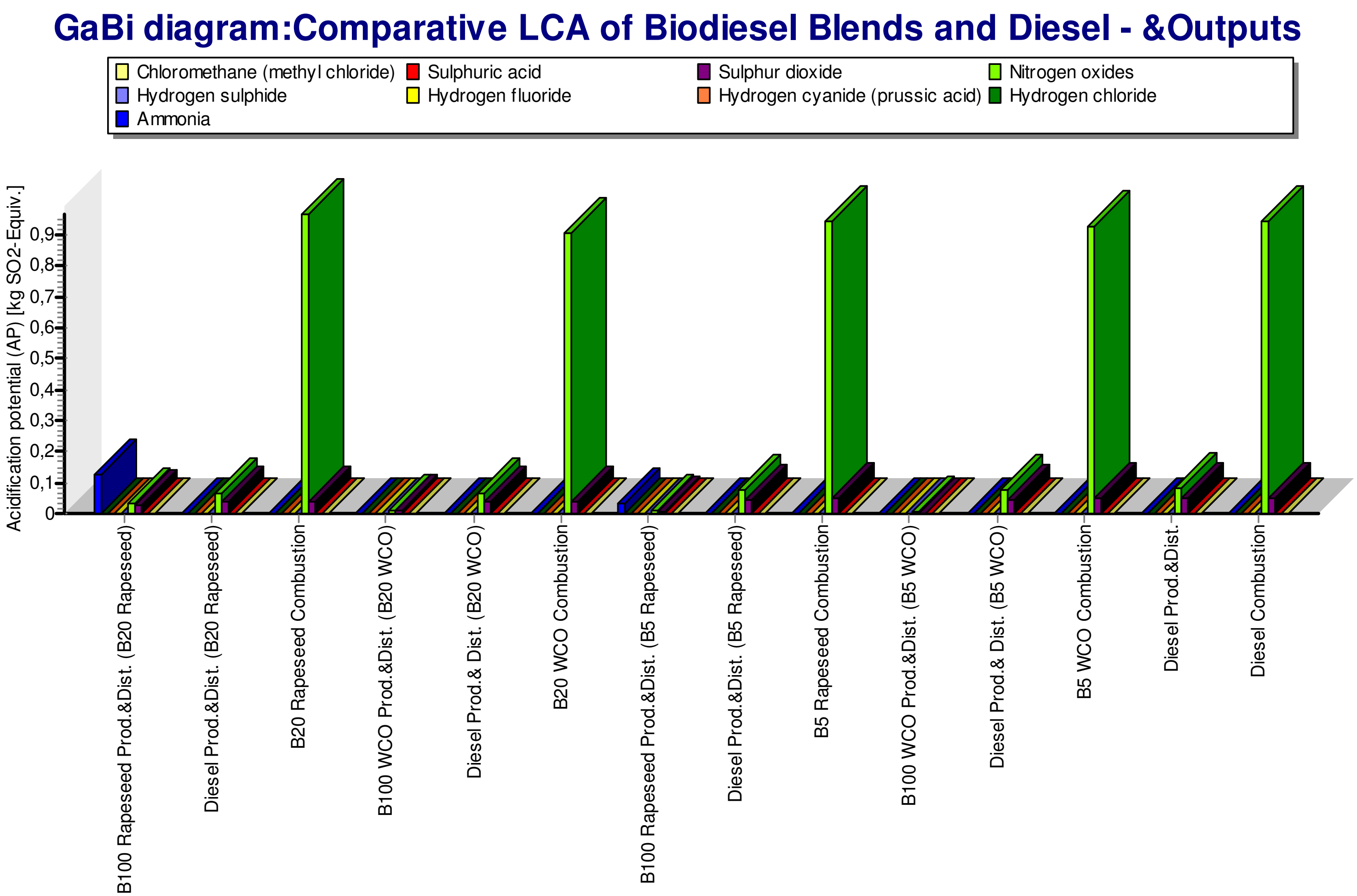

Figure D.6 : Acidification potentials of fuels (detailed view including emissions)

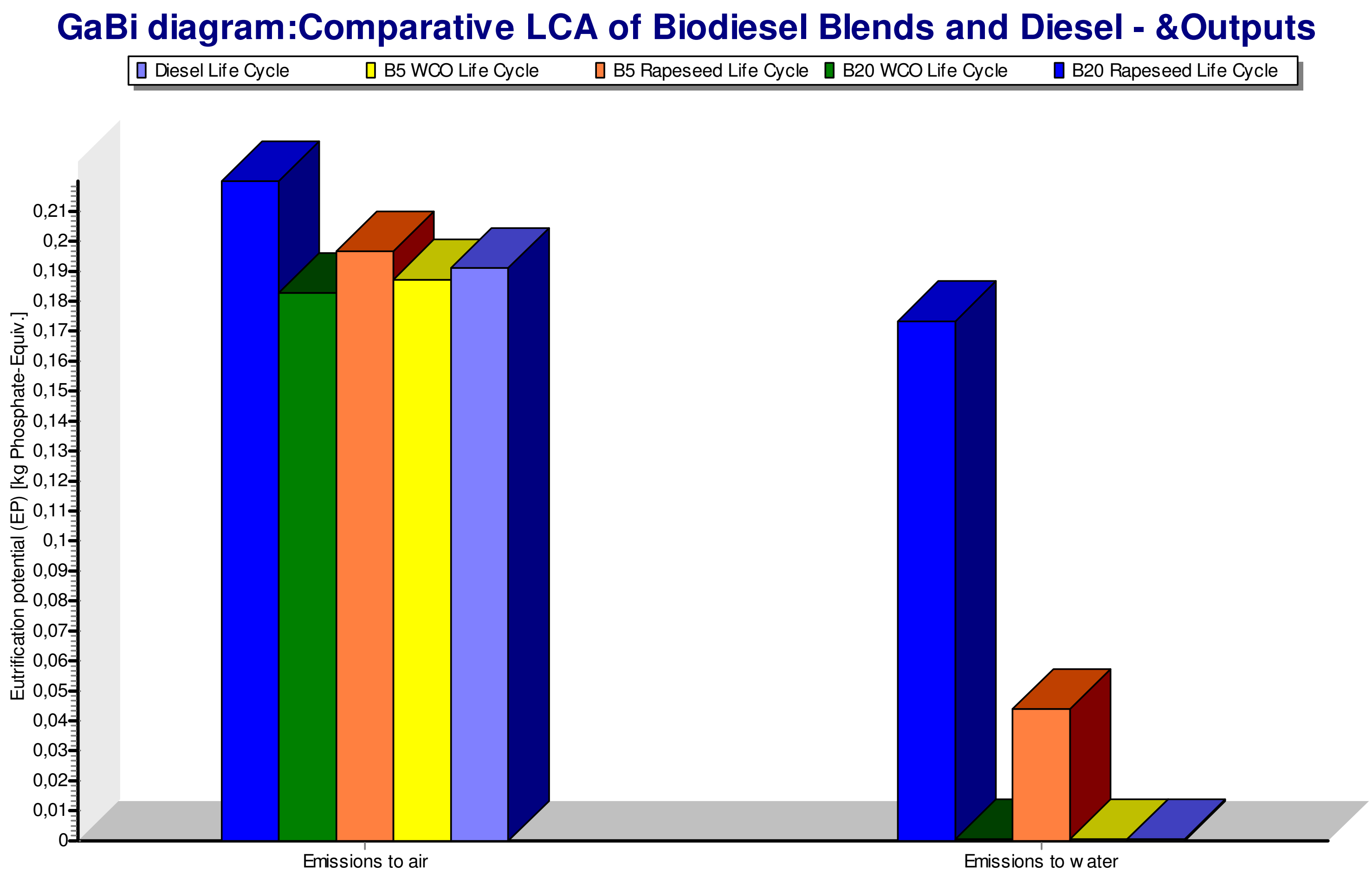

Figure D.7 : Eutrophication potentials of fuels.

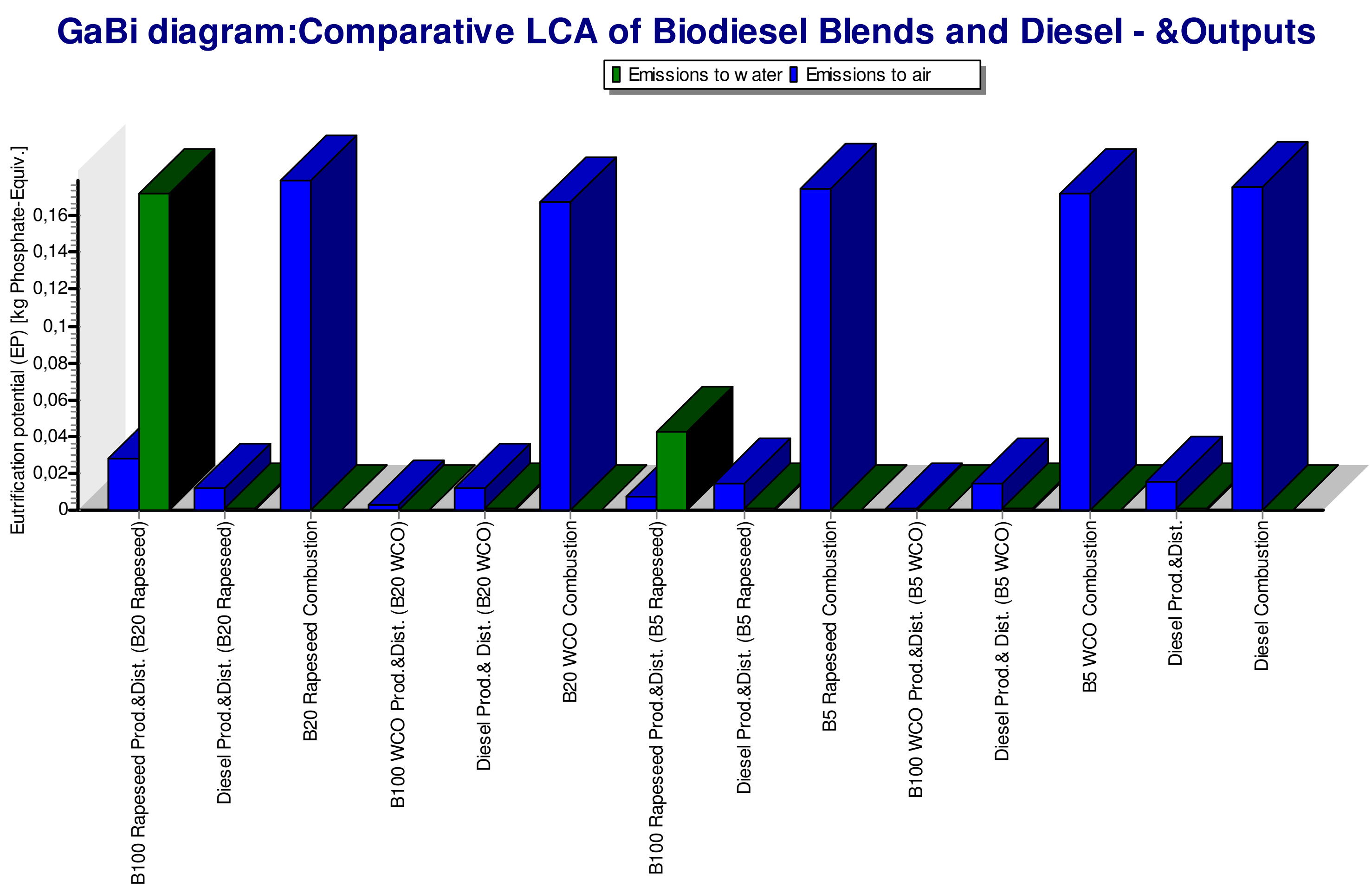

Figure D.8 : Eutrophication potentials of fuels (detailed view).

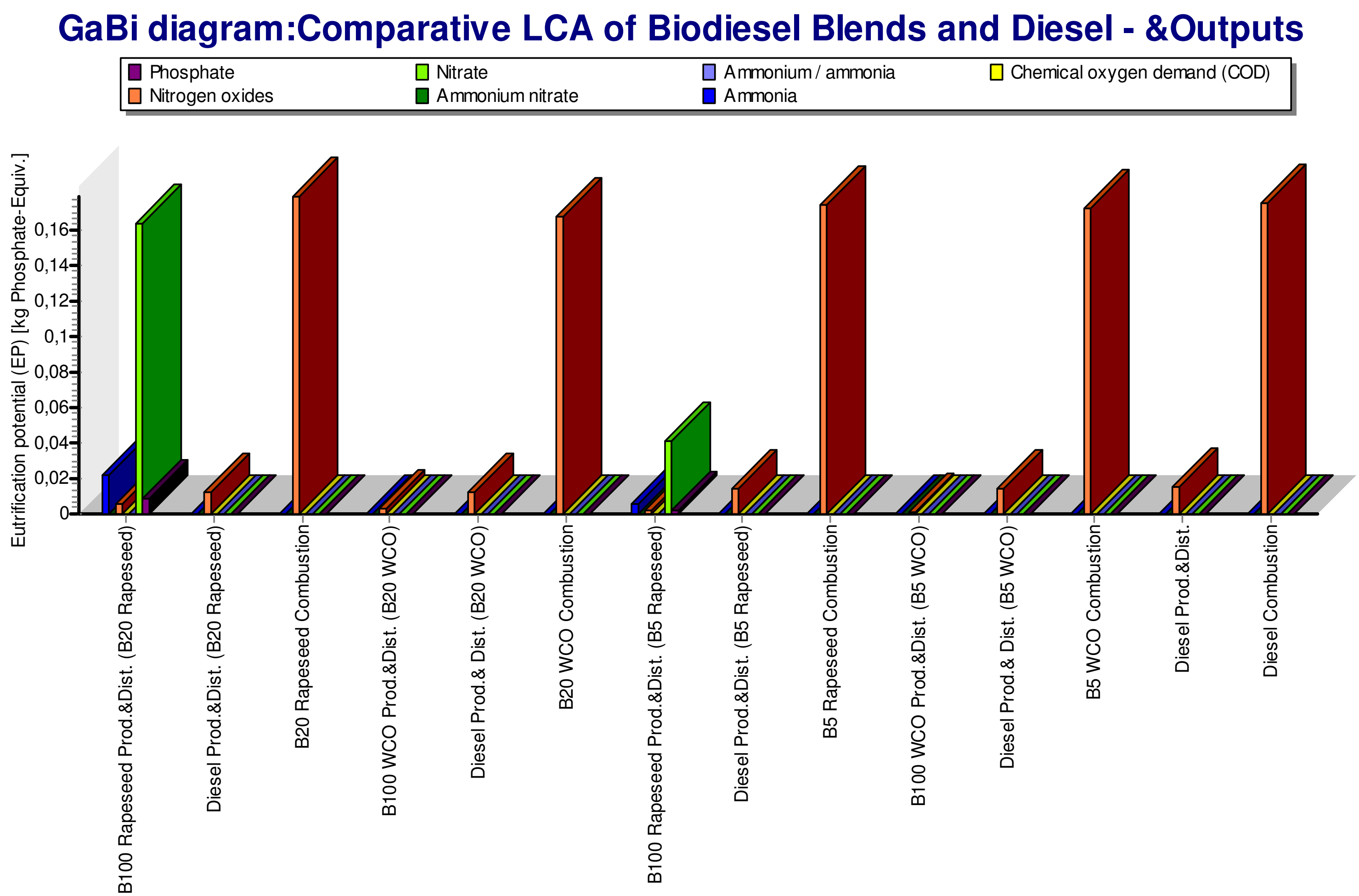

Figure D.9 : Eutrophication potentials of fuels (detailed view including emissions)

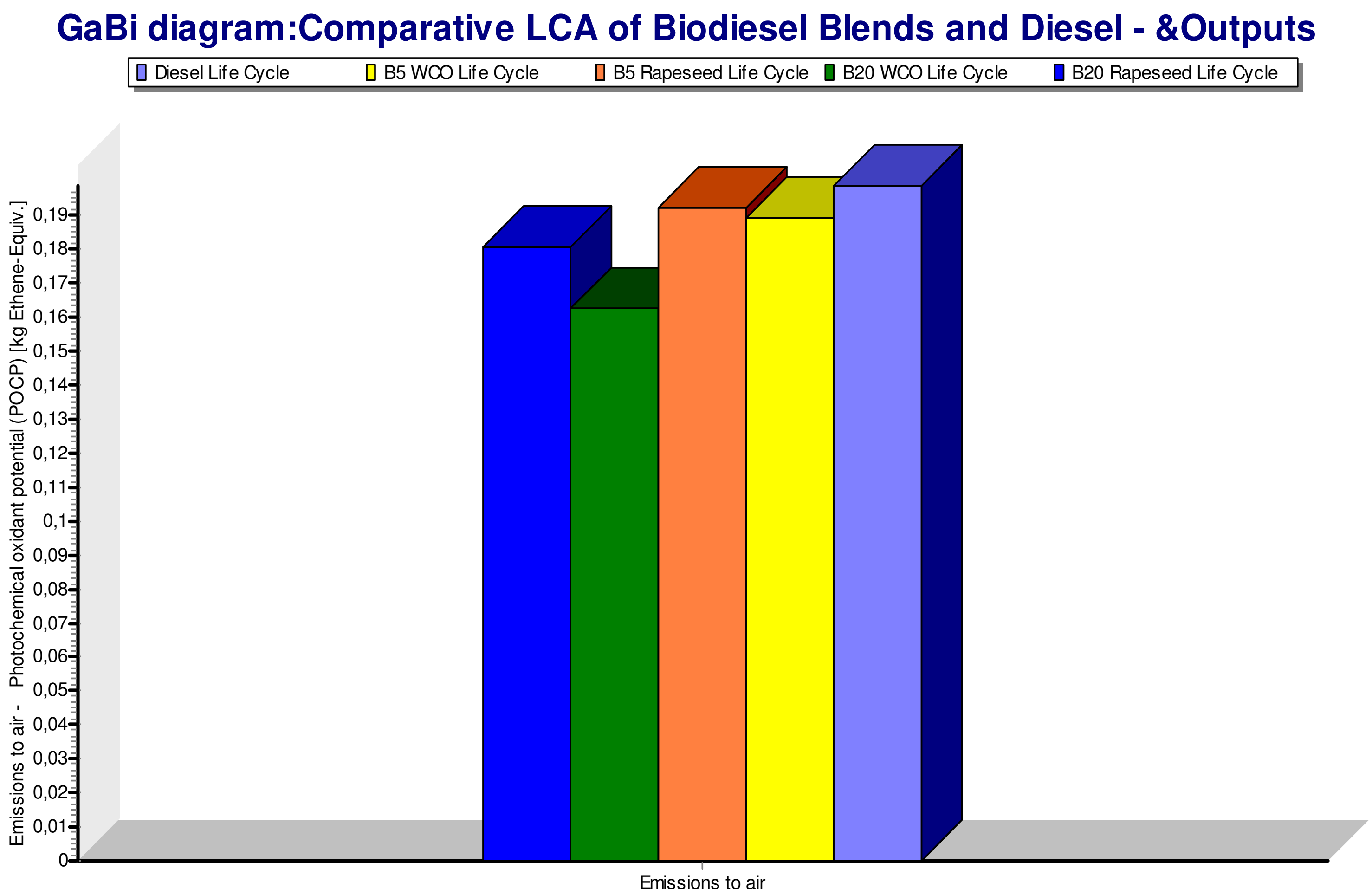

Figure D.10 : Photochemical oxidant formation potentials of fuels.

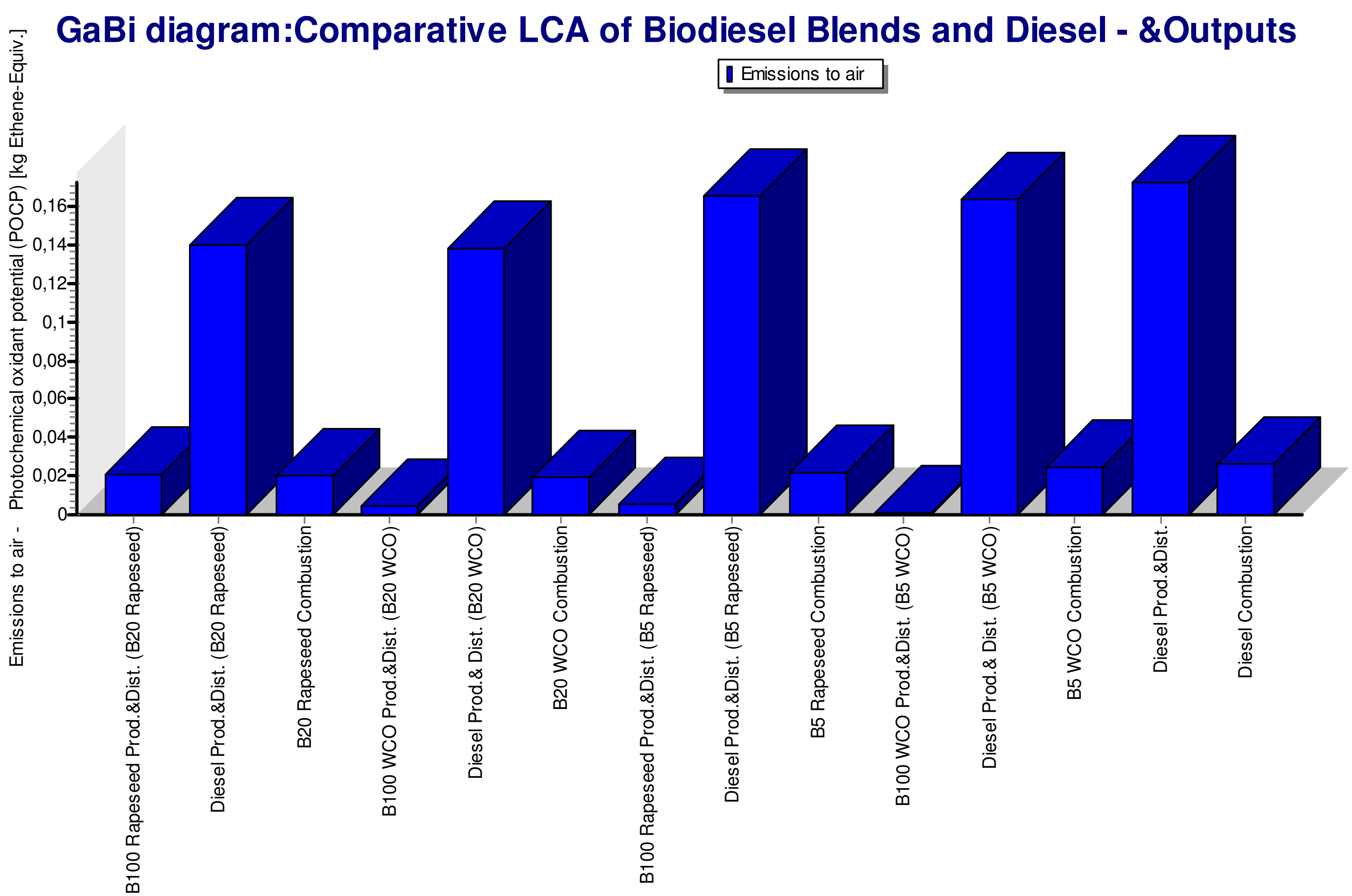

Figure D.11 : Photochemical oxidant formation potentials of fuels (detailed view).

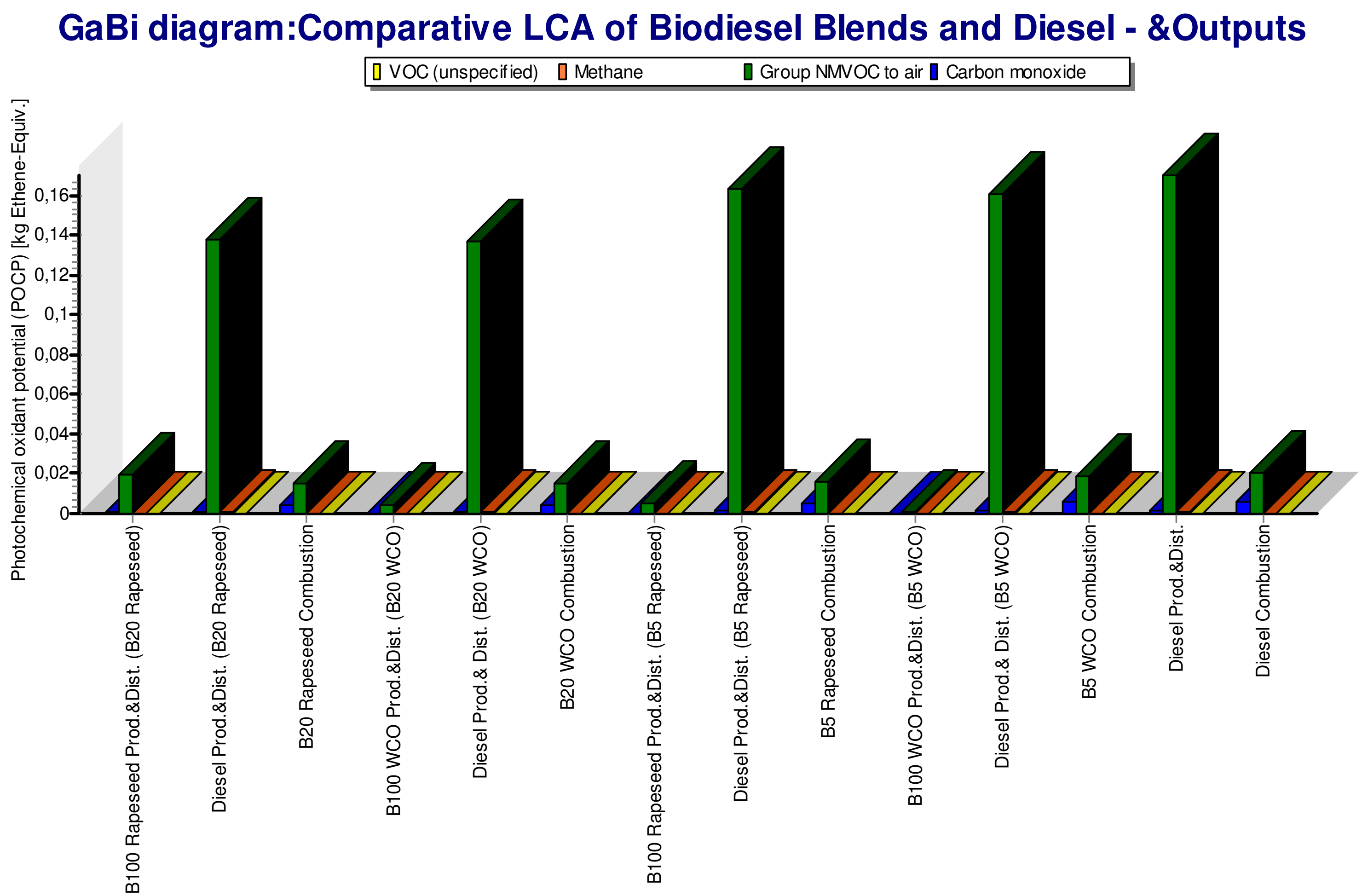

Figure D.12 : Photochemical oxidant formation potentials of fuels (detailed view including emissions)

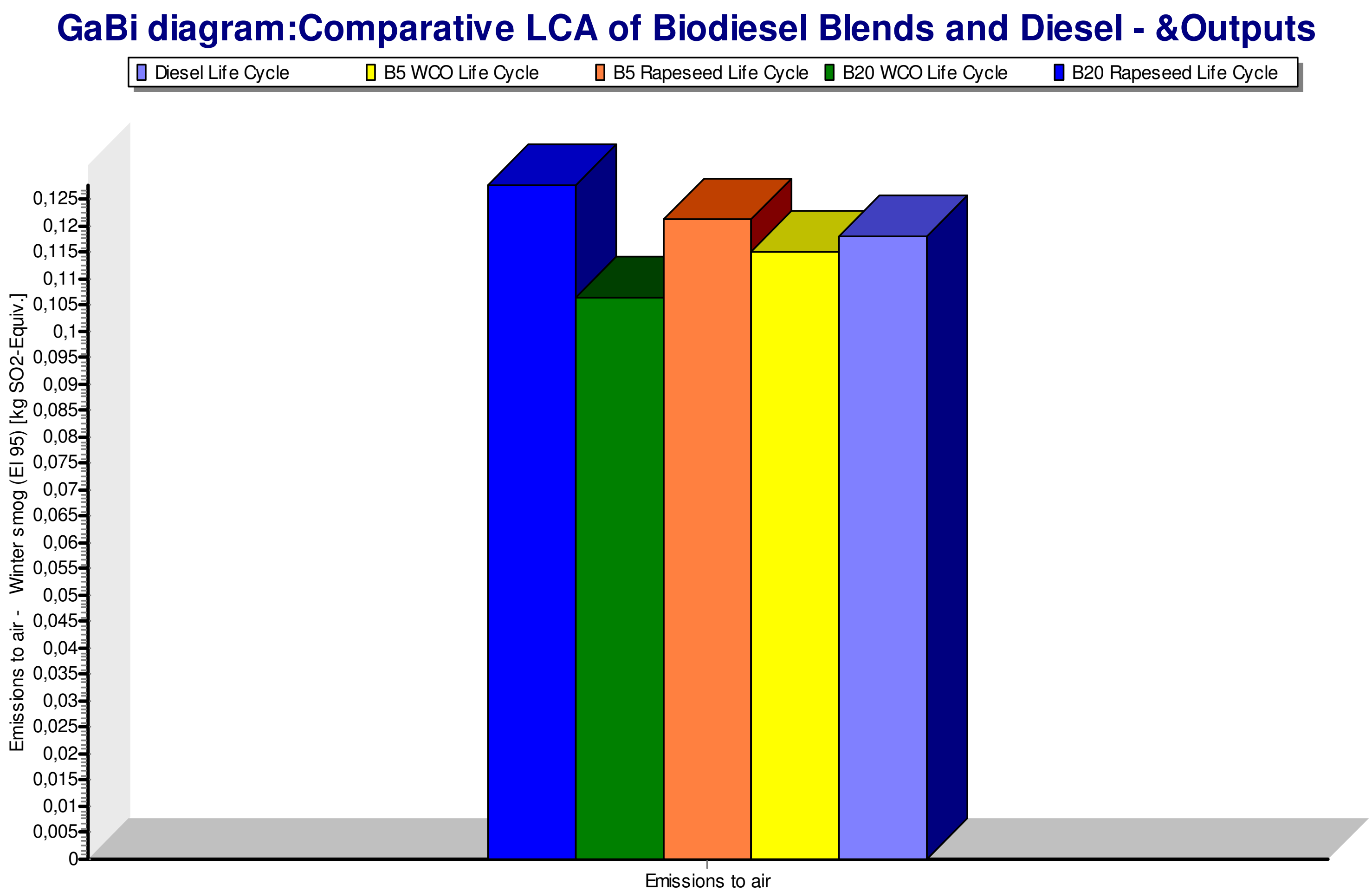

Figure D.13 : Winter smog potentials of fuels.

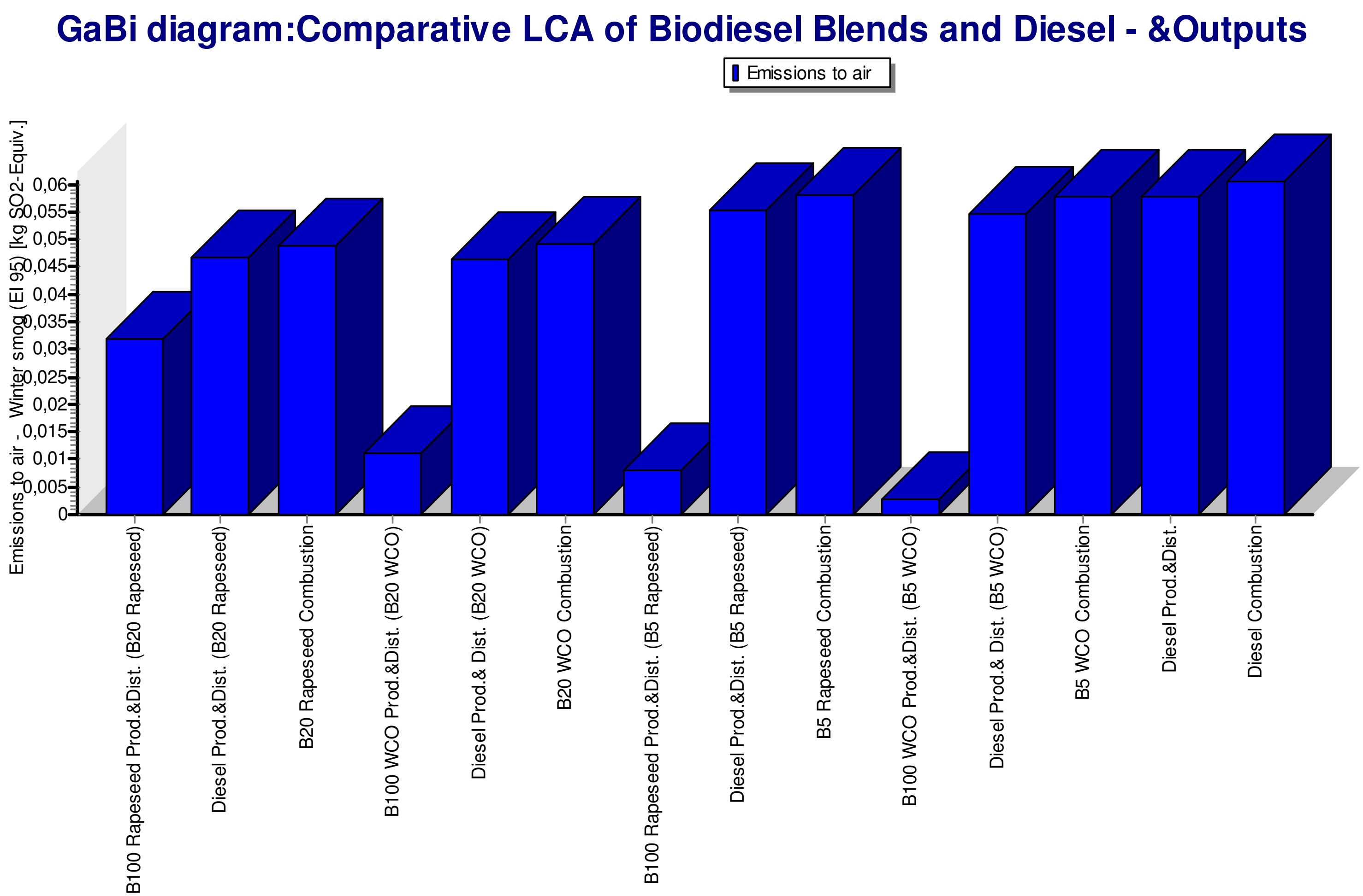

Figure D.14 : Winter smog potentials of fuels (detailed view).

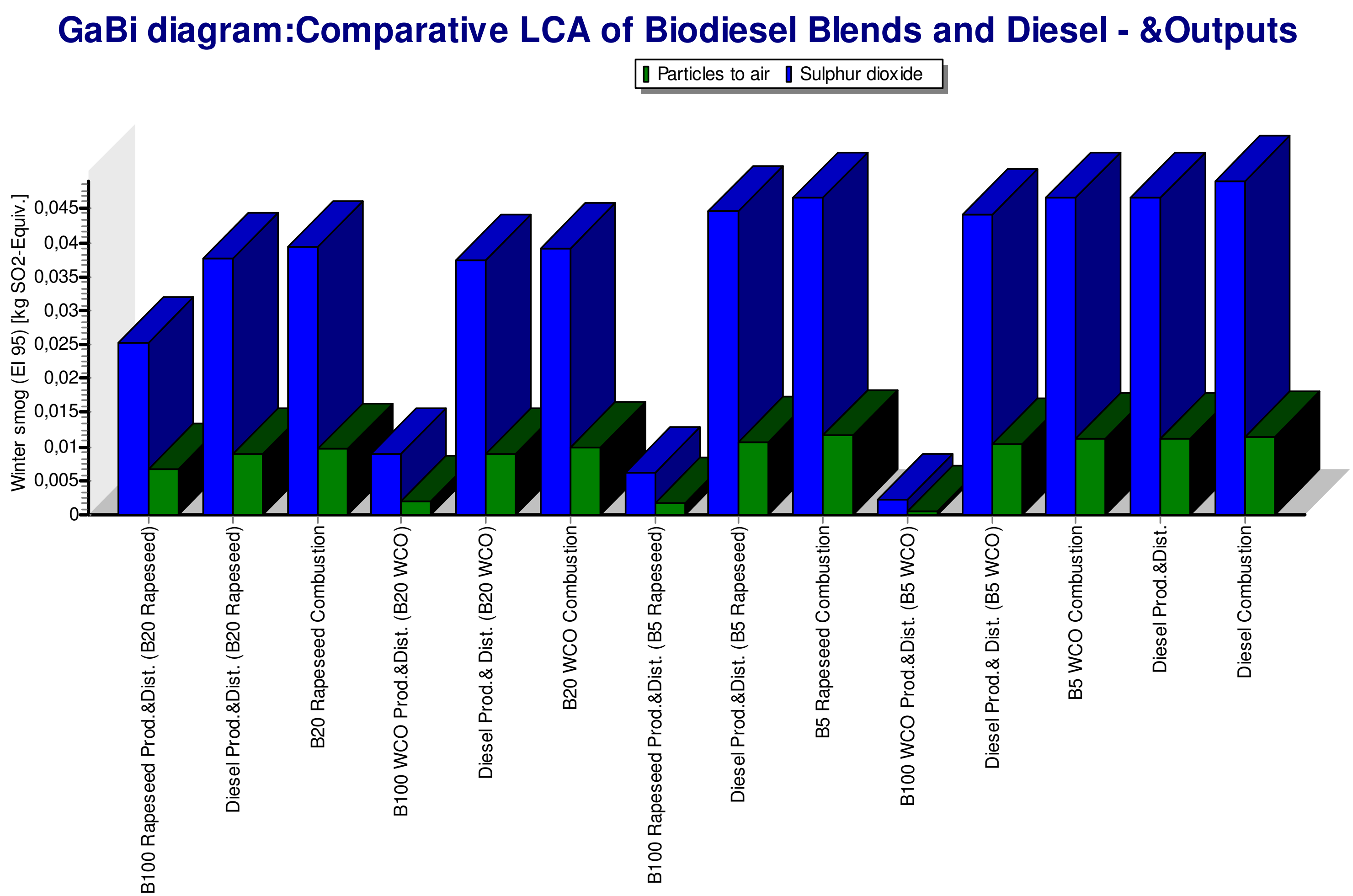

Figure D.15 : Winter smog potentials of fuels (detailed view including emissions)

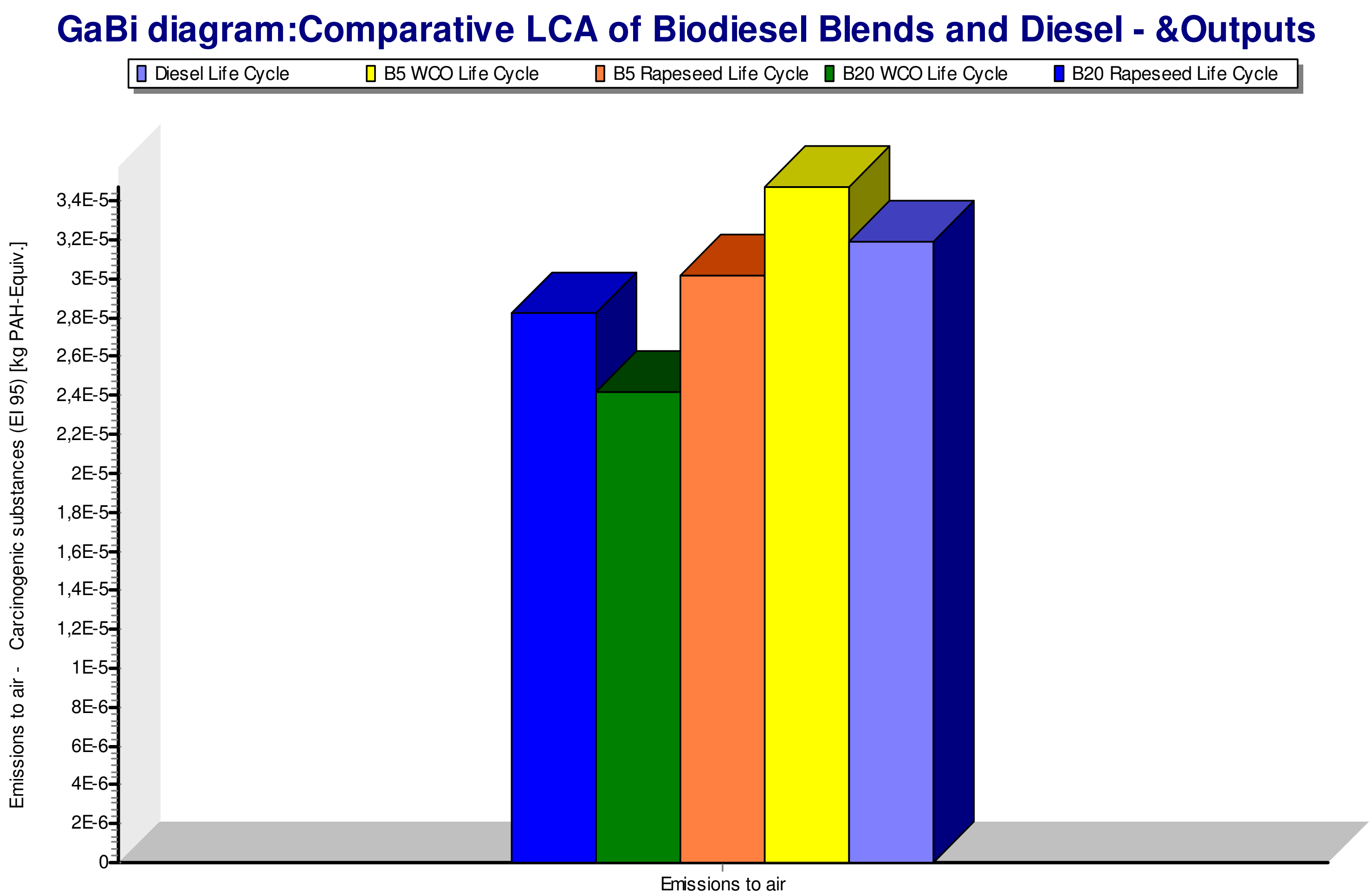

Figure D.16 : Carcinogenic potentials of fuels.

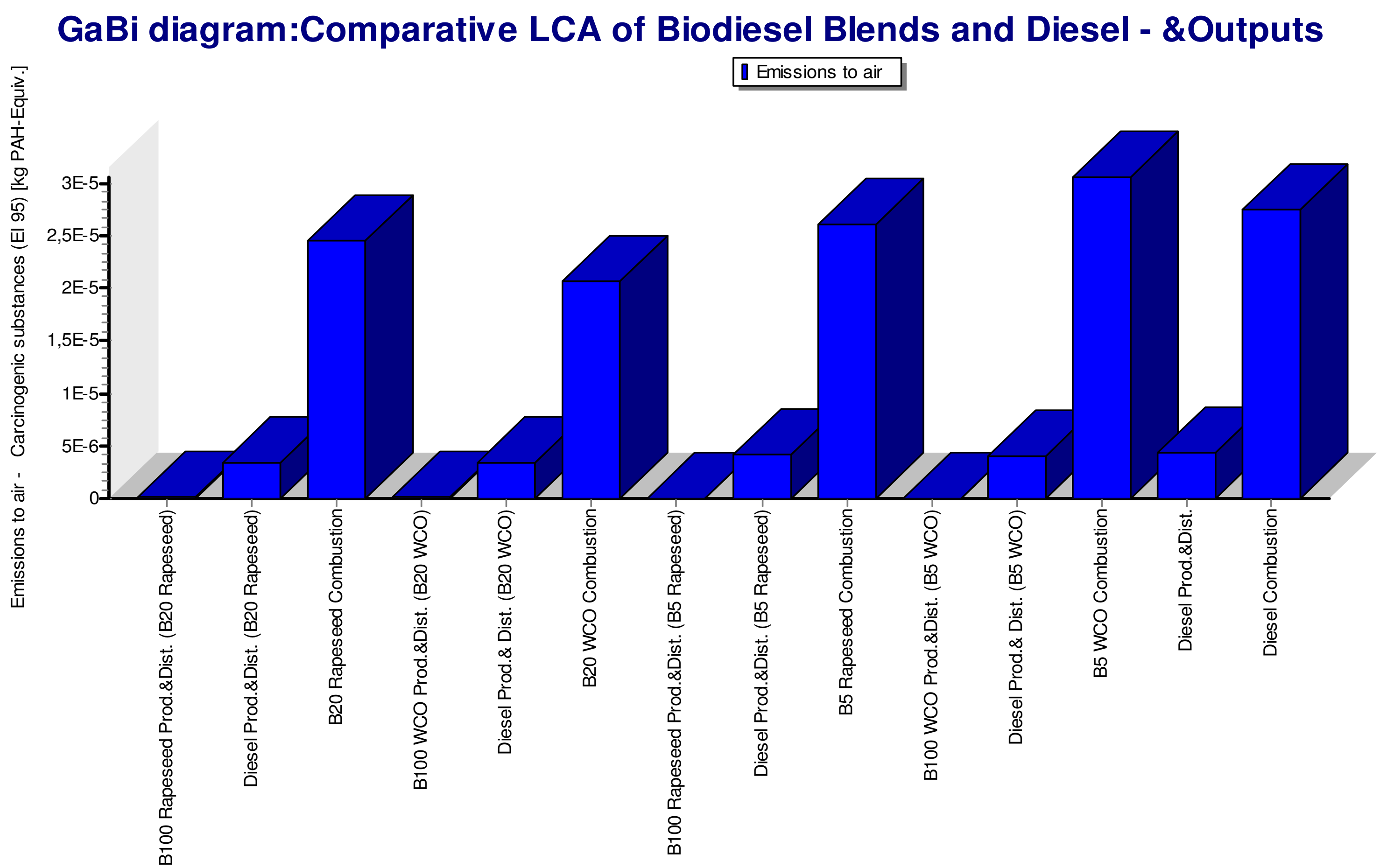

Figure D.17 : Carcinogenic potentials of fuels (detailed view).

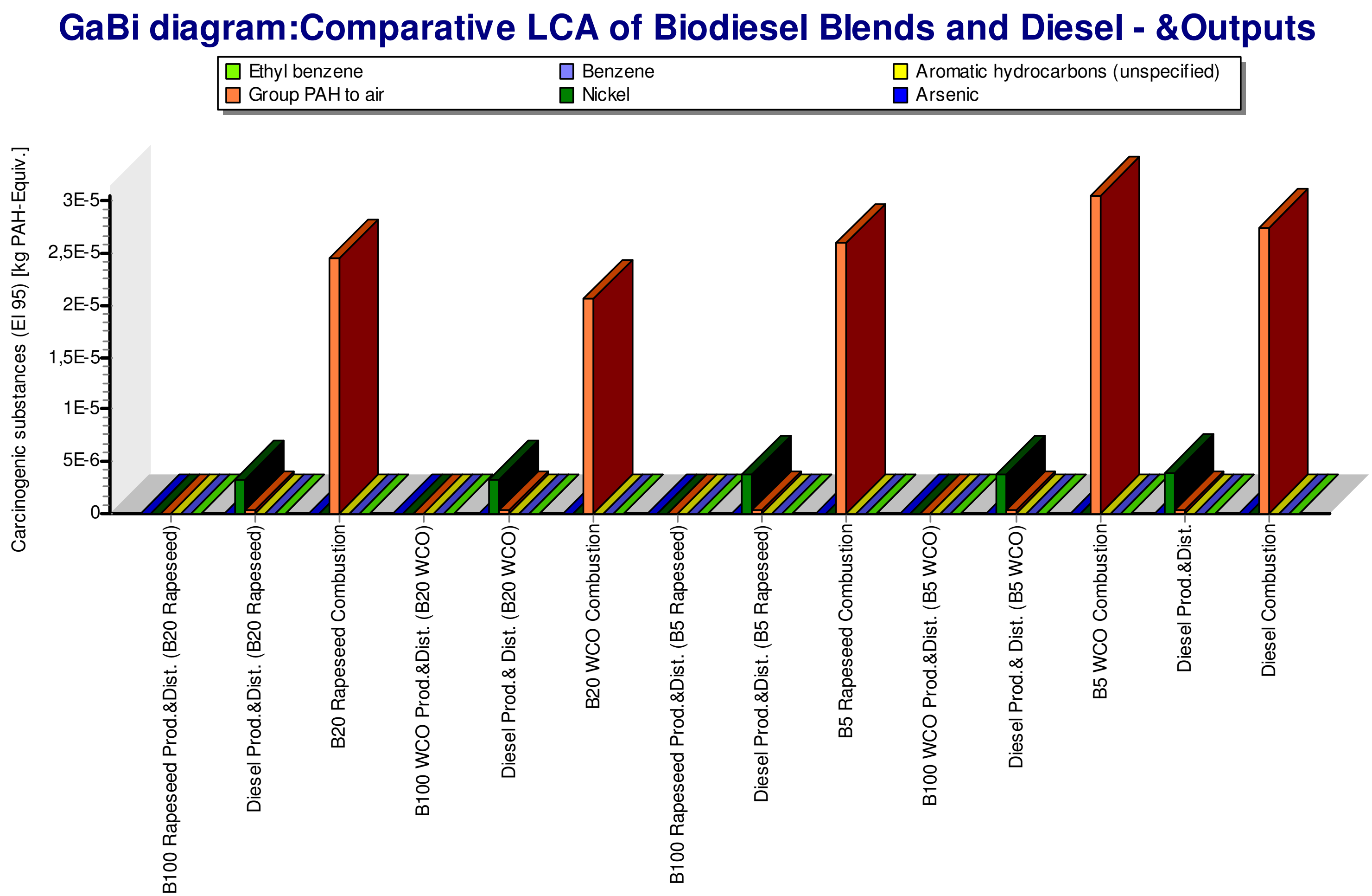

Figure D.18 : Carcinogenic potentials of fuels (detailed view including emissions)

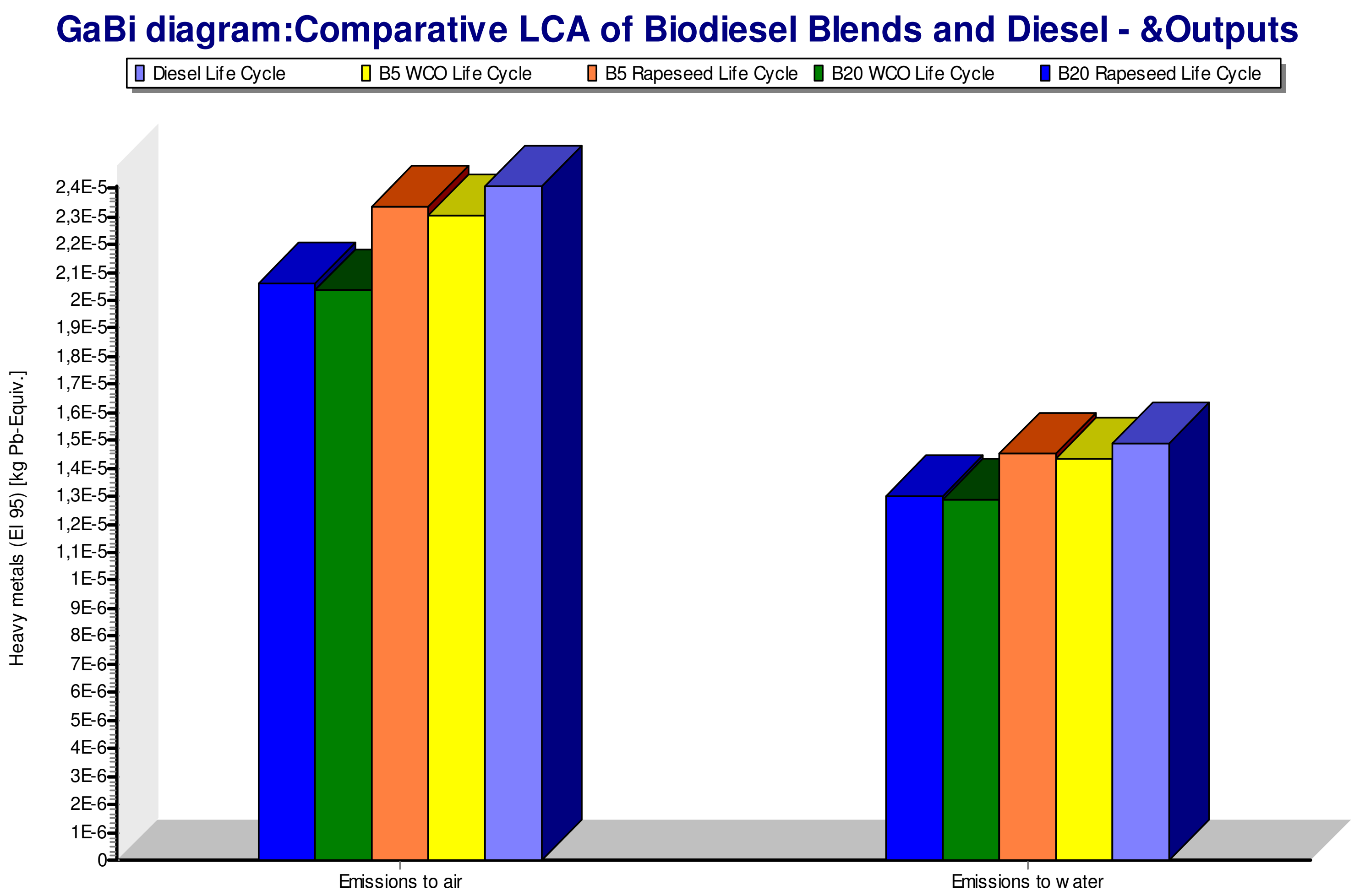

Figure D.19 : Heavy metal potentials of fuels.

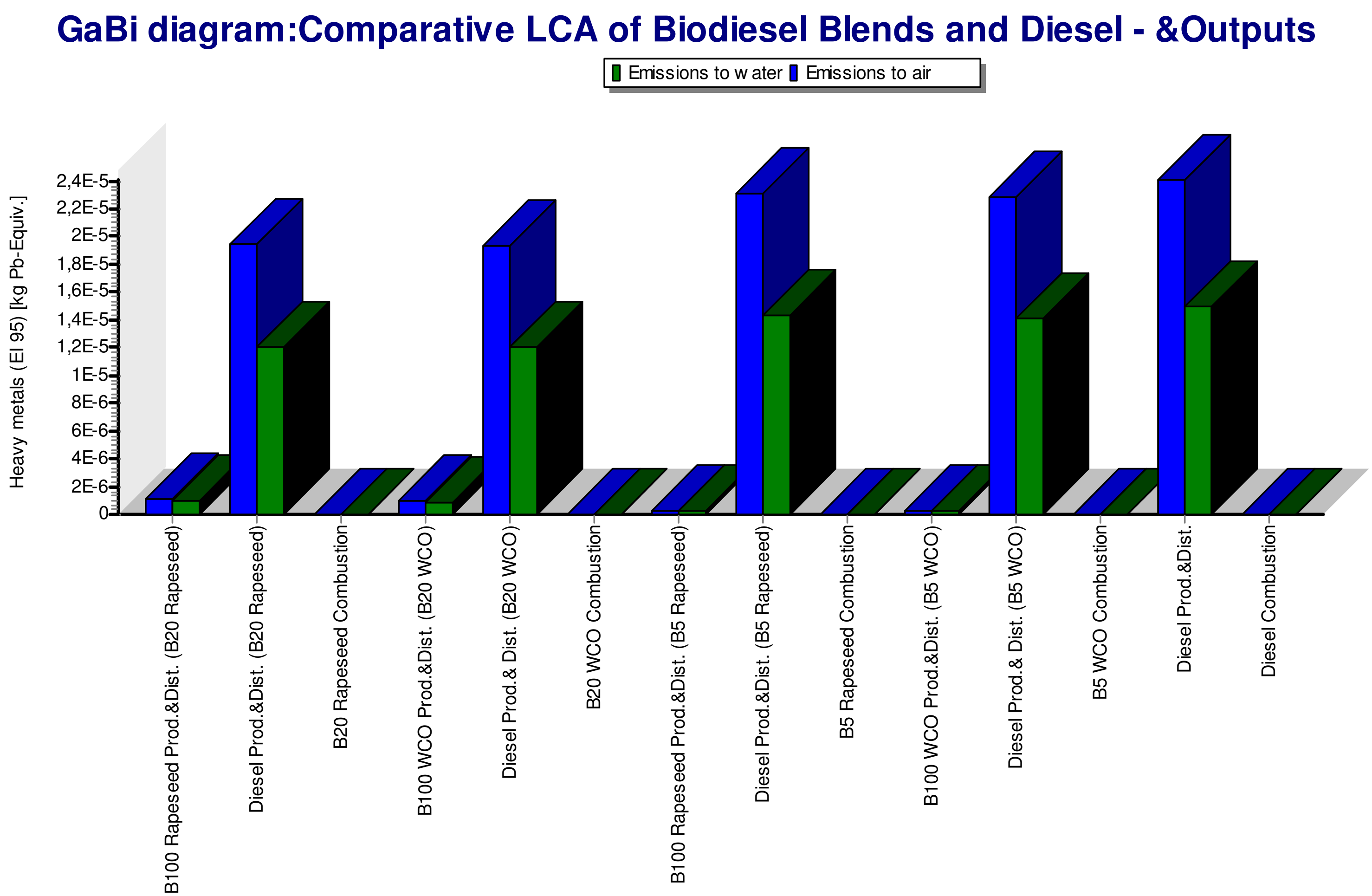

Figure D.20 : Heavy metal potentials of fuels (detailed view).

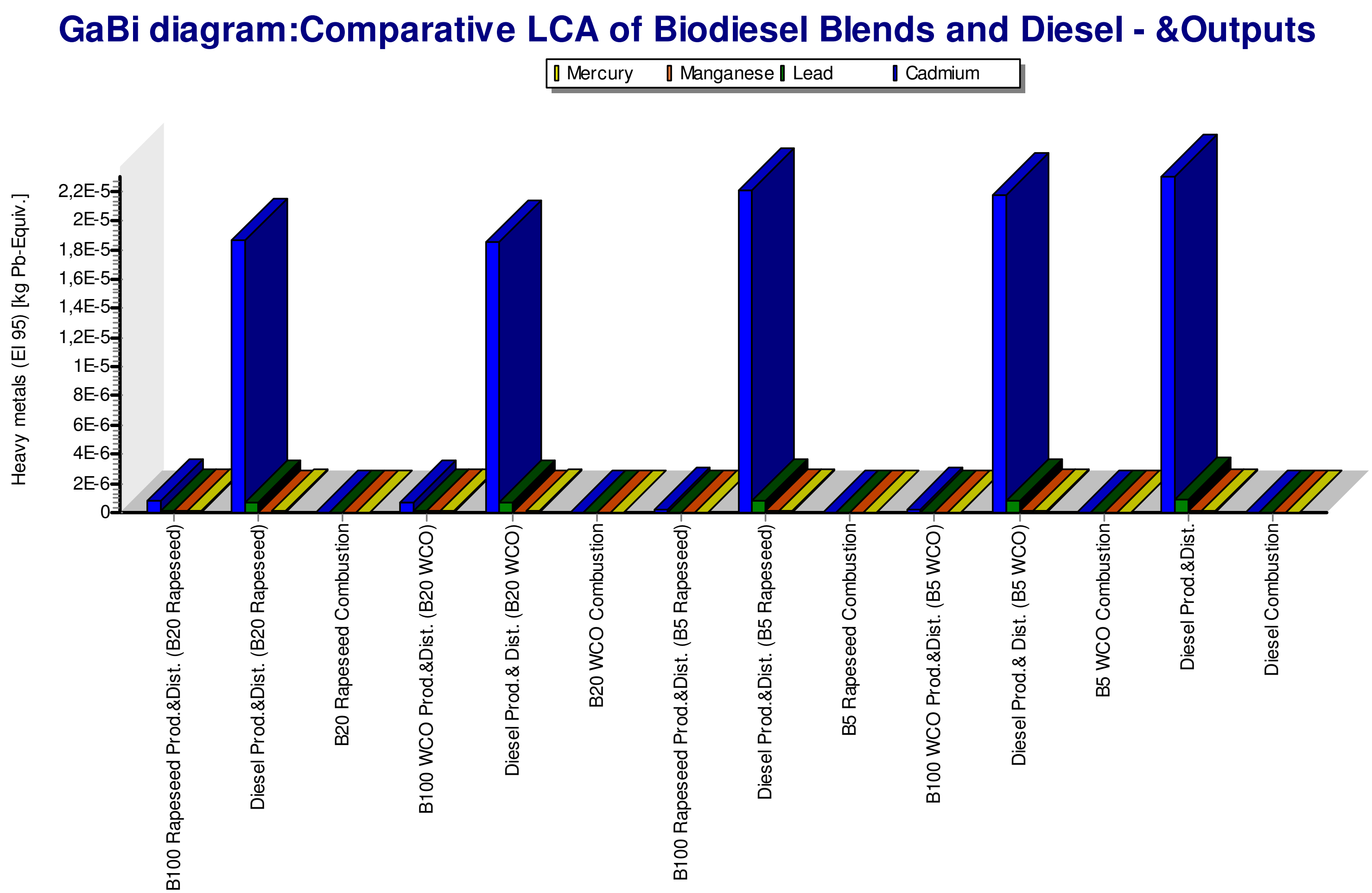

Figure D.21 : Heavy metal potentials of fuels (detailed view including air emissions)

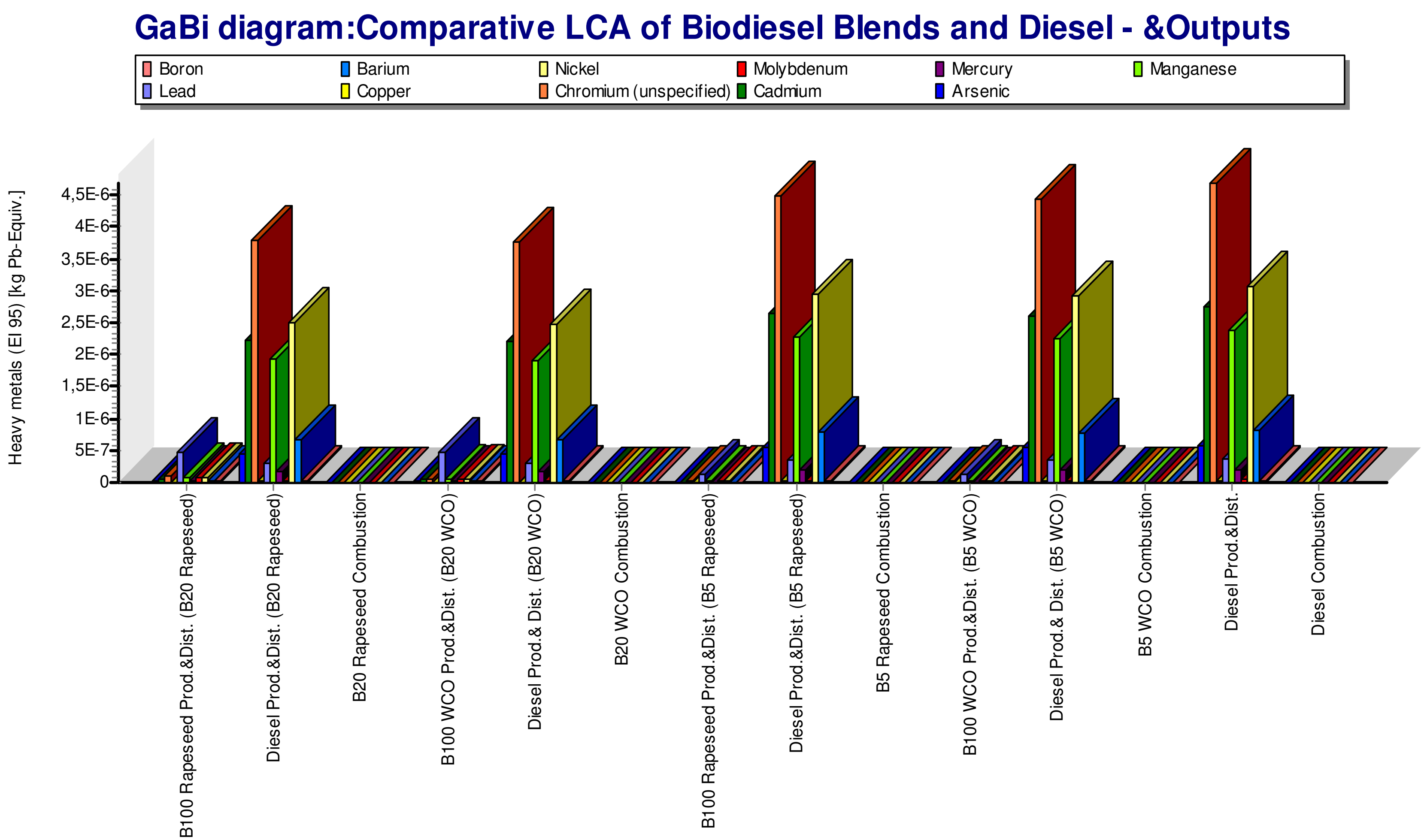

Figure D.22 : Heavy metal potentials of fuels (detailed view including water emissions)

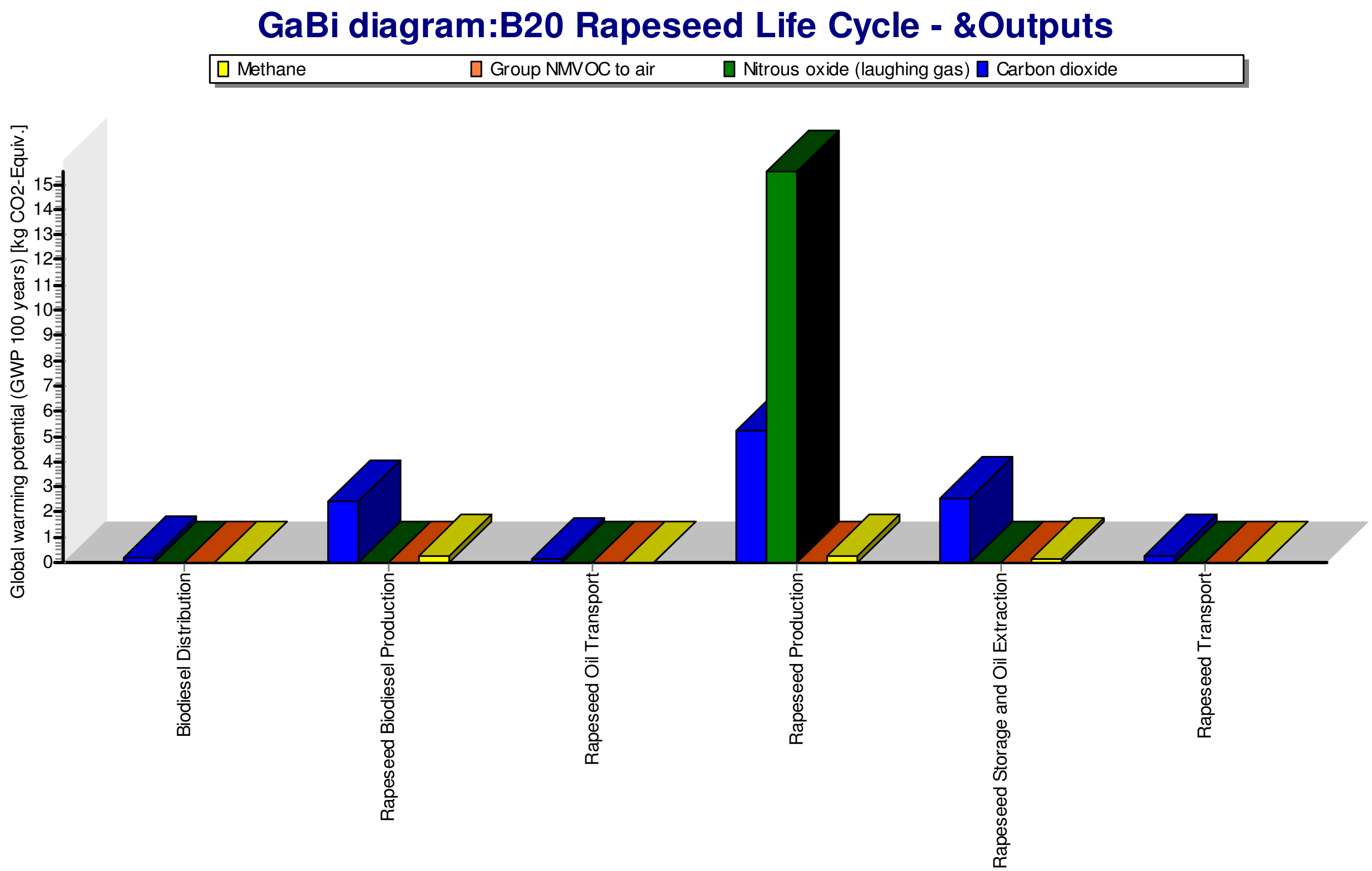

Figure D.23 : Detailed analysis of global warming potential for rapeseed biodiesel (B100) production for B20 rapeseed

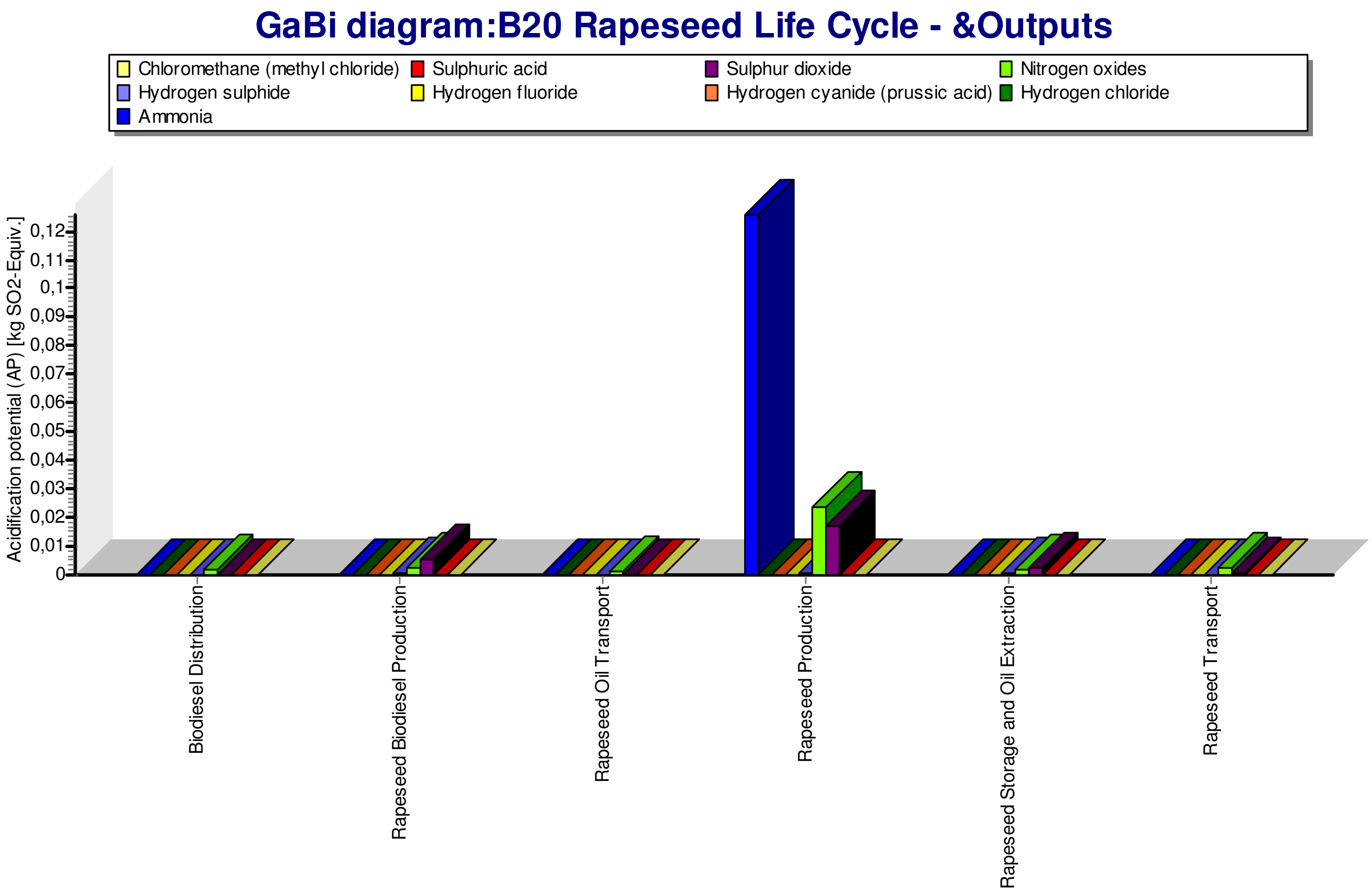

Figure D.24 : Detailed analysis of acidification potential for rapeseed biodiesel (B100) production for B20 rapeseed

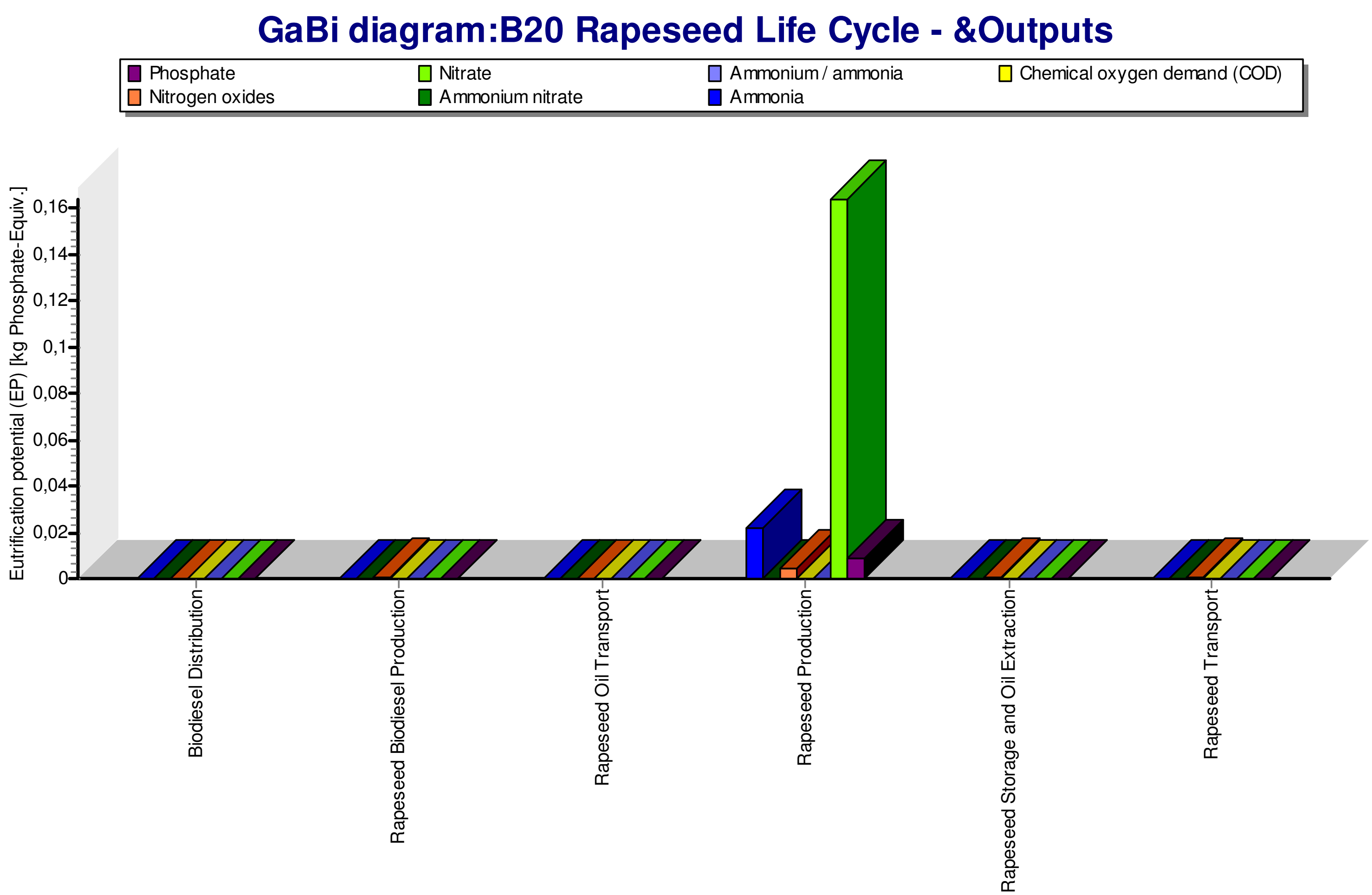

Figure D.25 : Detailed analysis of eutrophication potential for rapeseed biodiesel (B100) production for B20 rapeseed

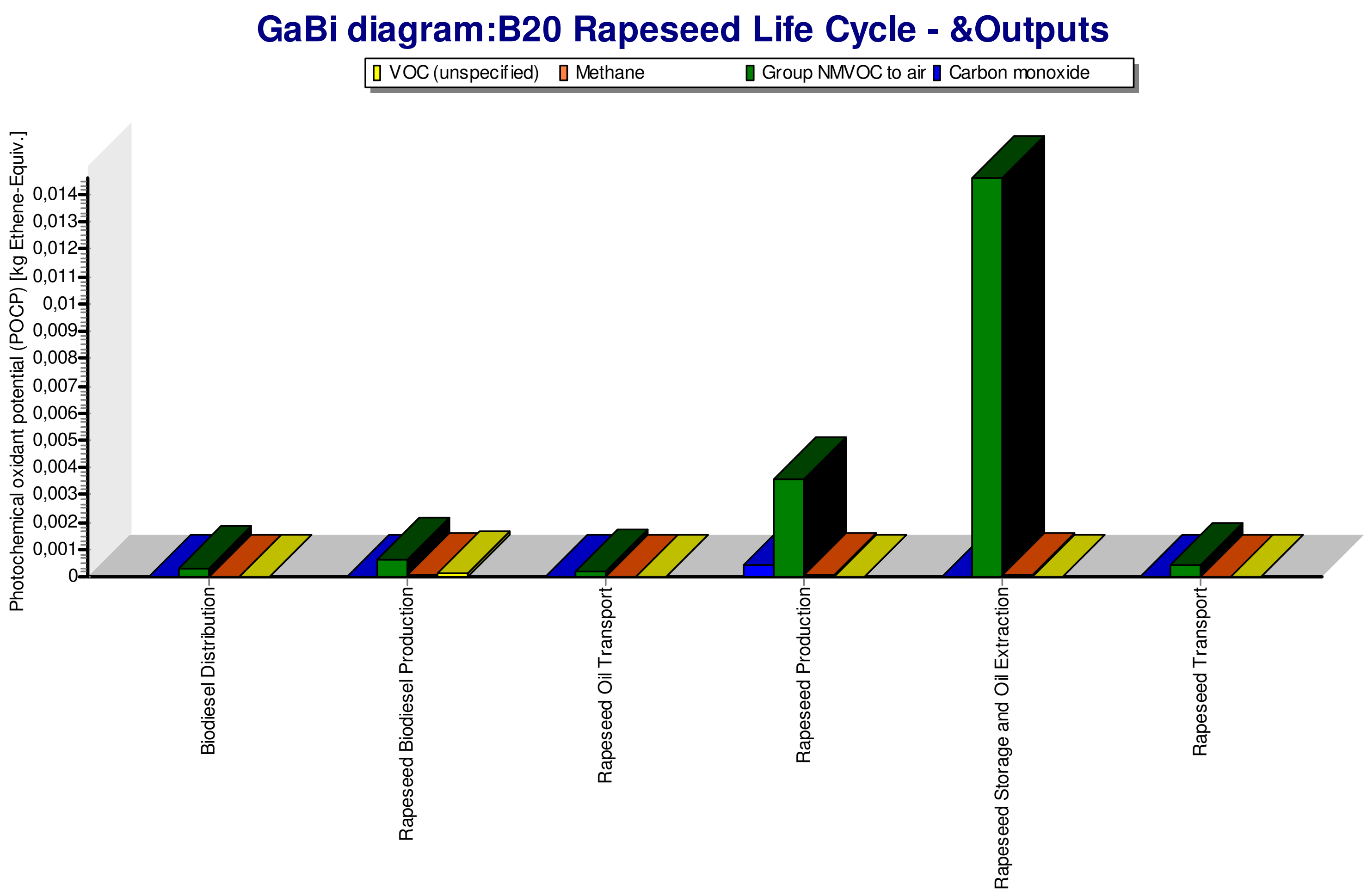

Figure D.26 : Detailed analysis of photochemical oxidant formation potential for rapeseed biodiesel (B100) production for B20 rapeseed

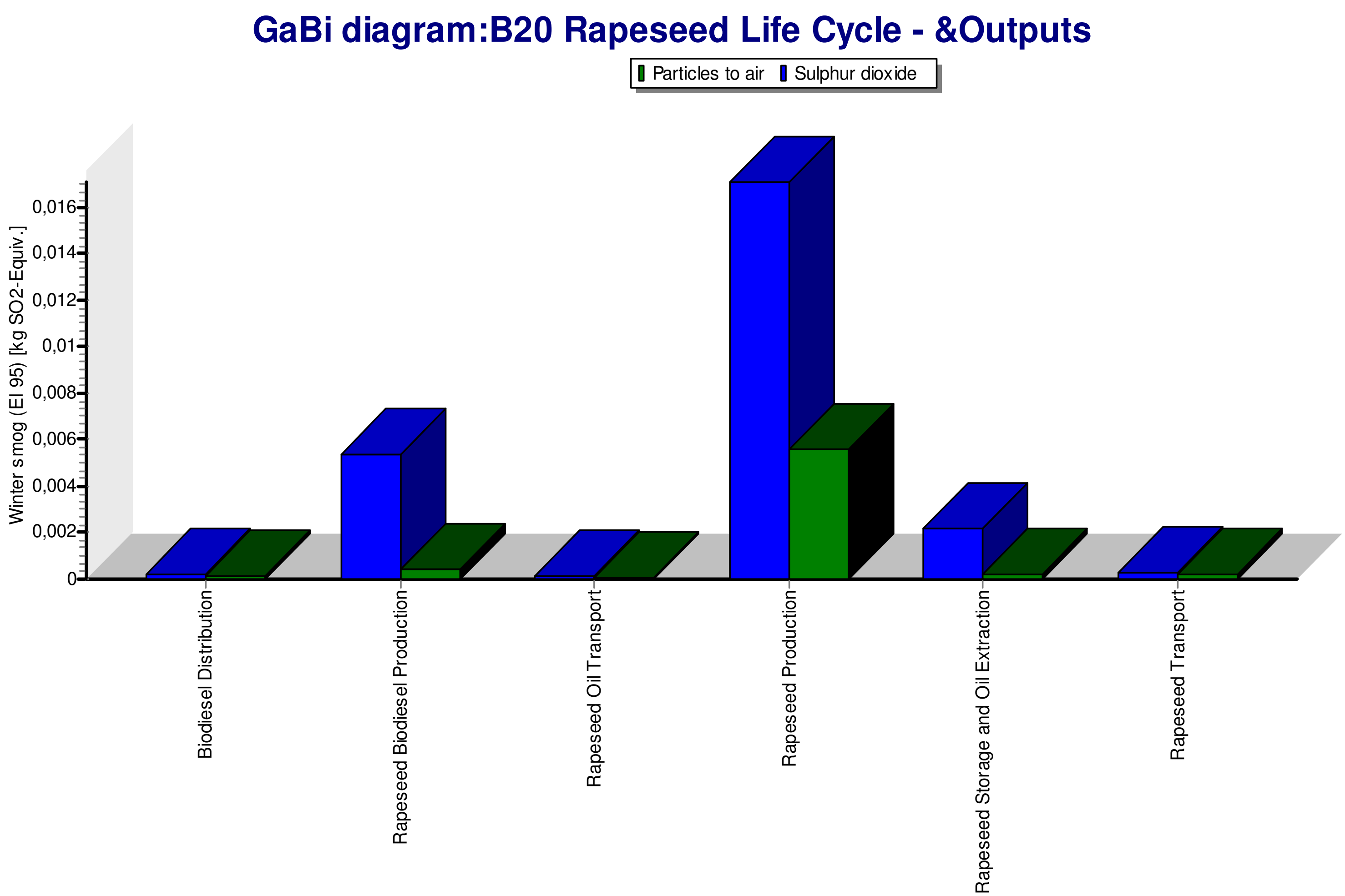

Figure D.27 : Detailed analysis of winter smog potential for rapeseed biodiesel (B100) production for B20 rapeseed

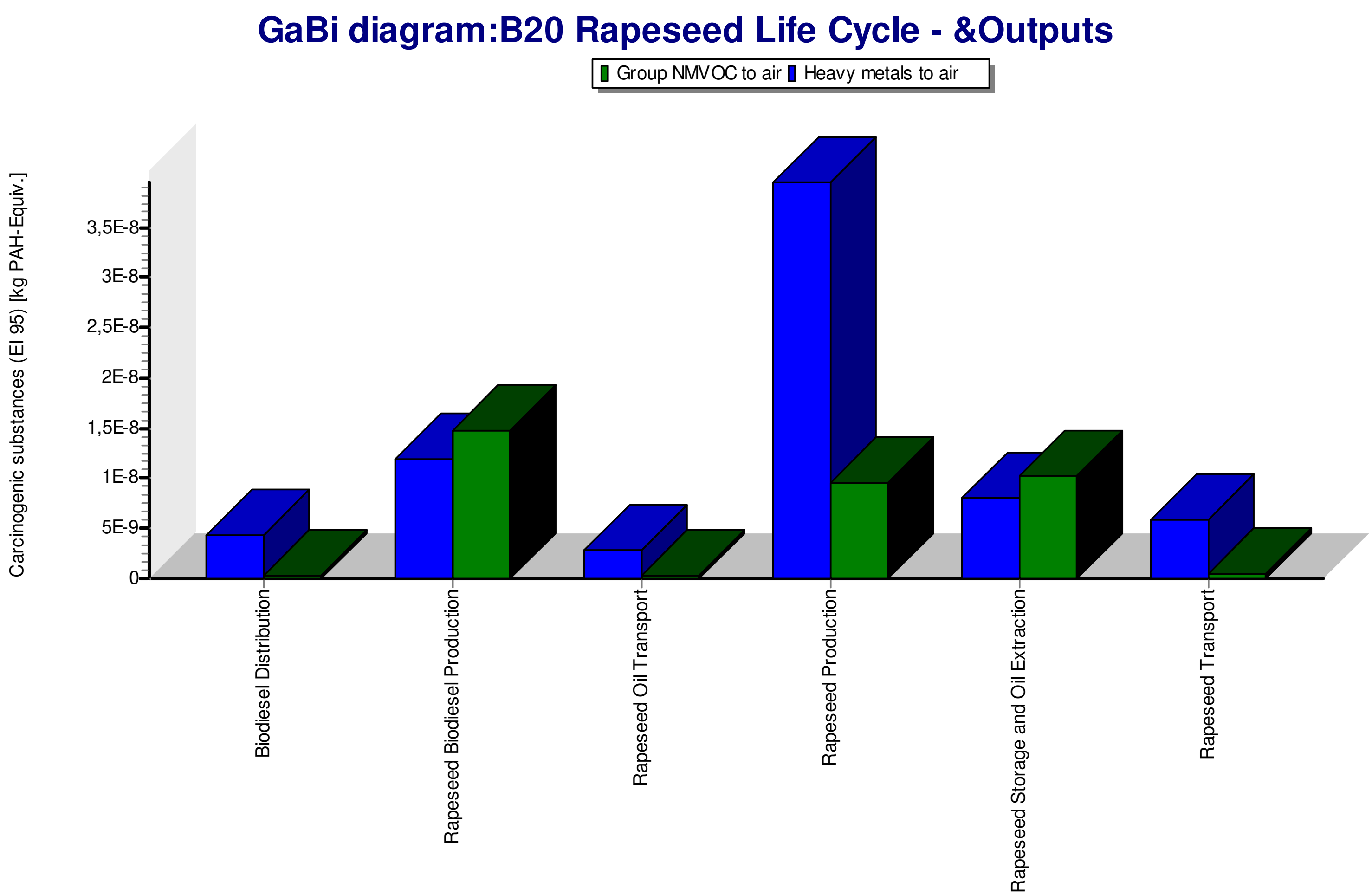

Figure D.28 : Detailed analysis of carcinogenic substances for rapeseed biodiesel (B100) production for B20 rapeseed

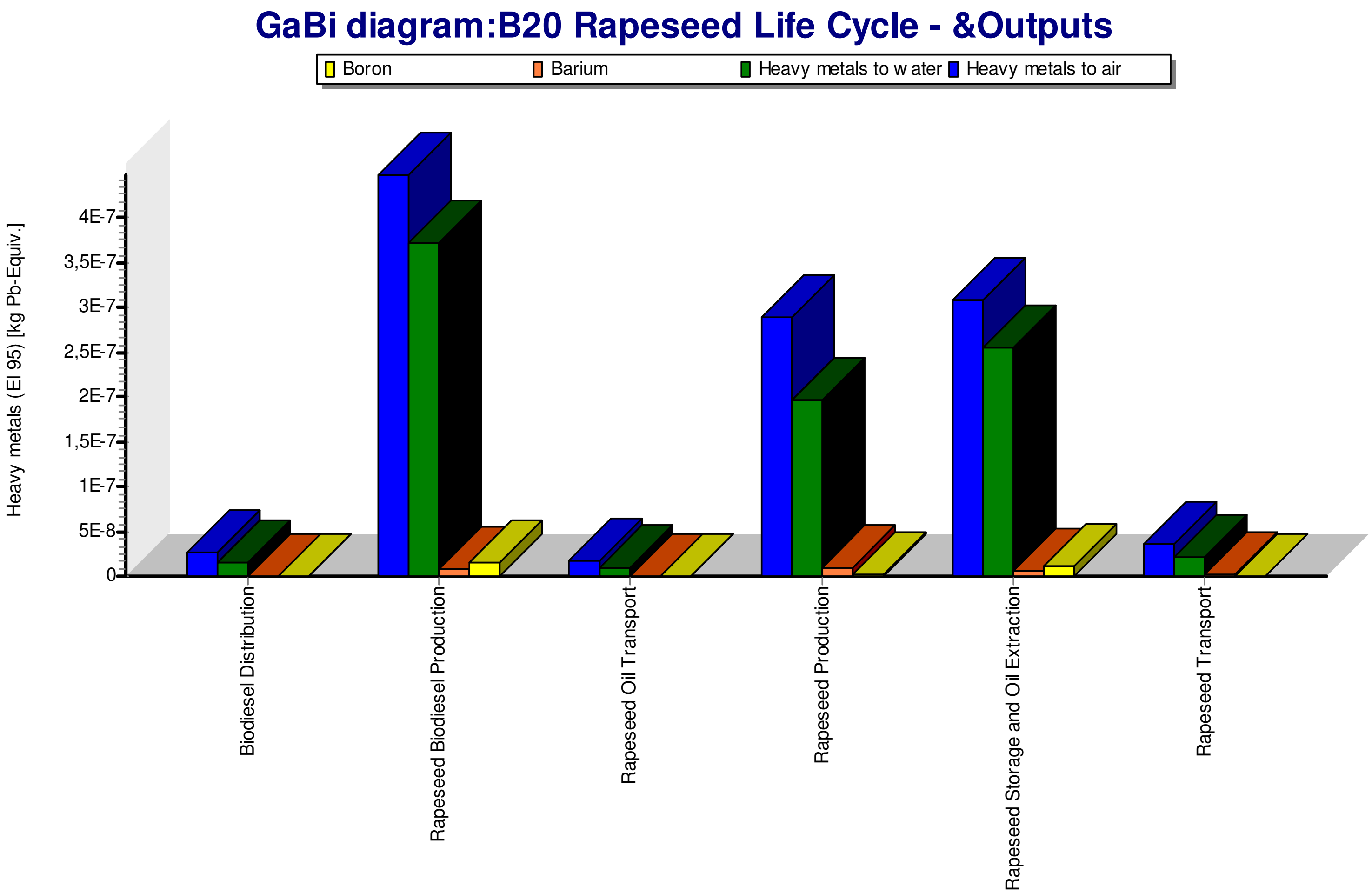

Figure D.29 : Detailed analysis of heavy metals for rapeseed biodiesel (B100) production for B20 rapeseed

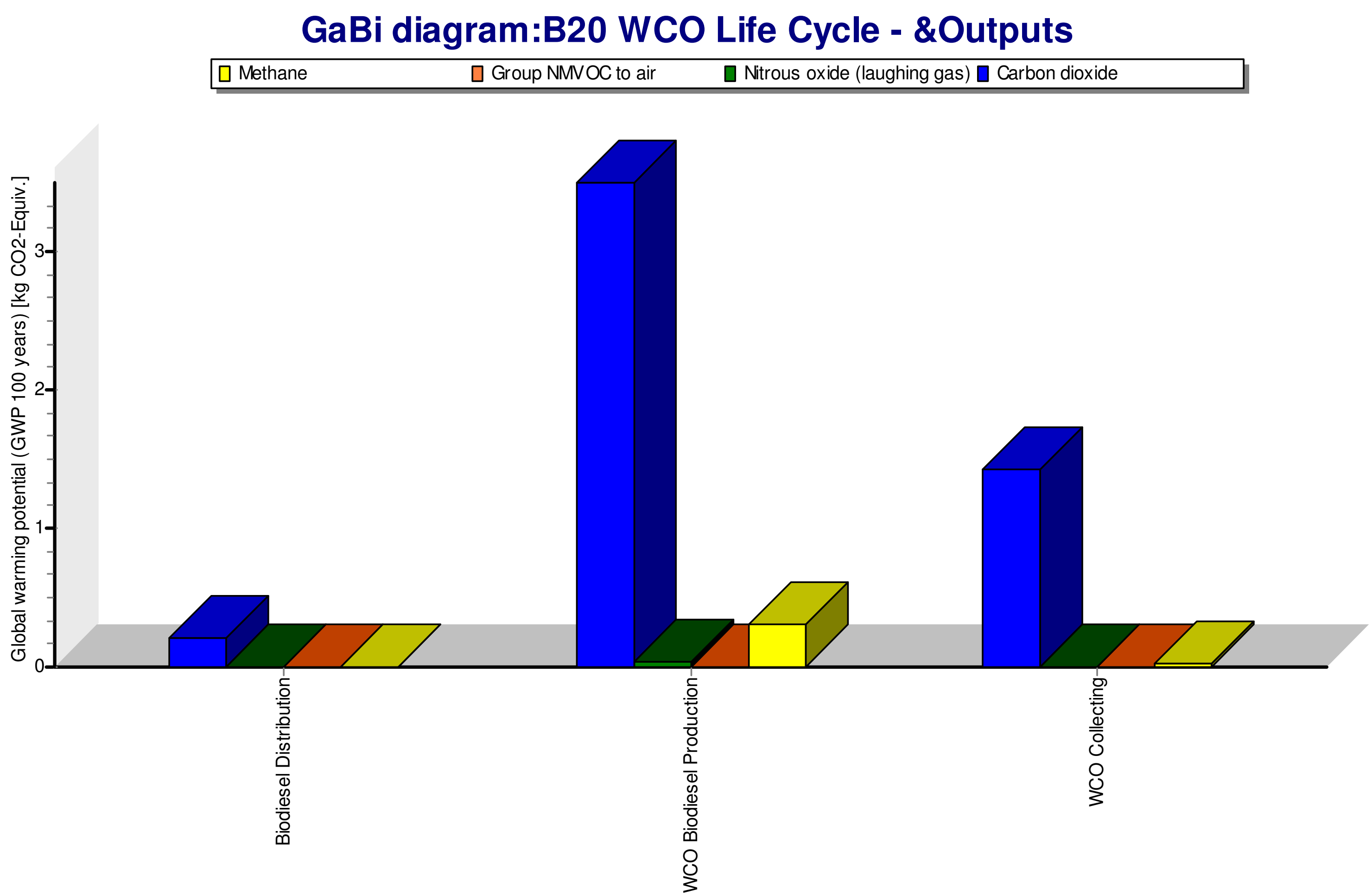

Figure D.30 : Detailed analysis of global warming potential for WCO biodiesel (B100) production for B20 WCO

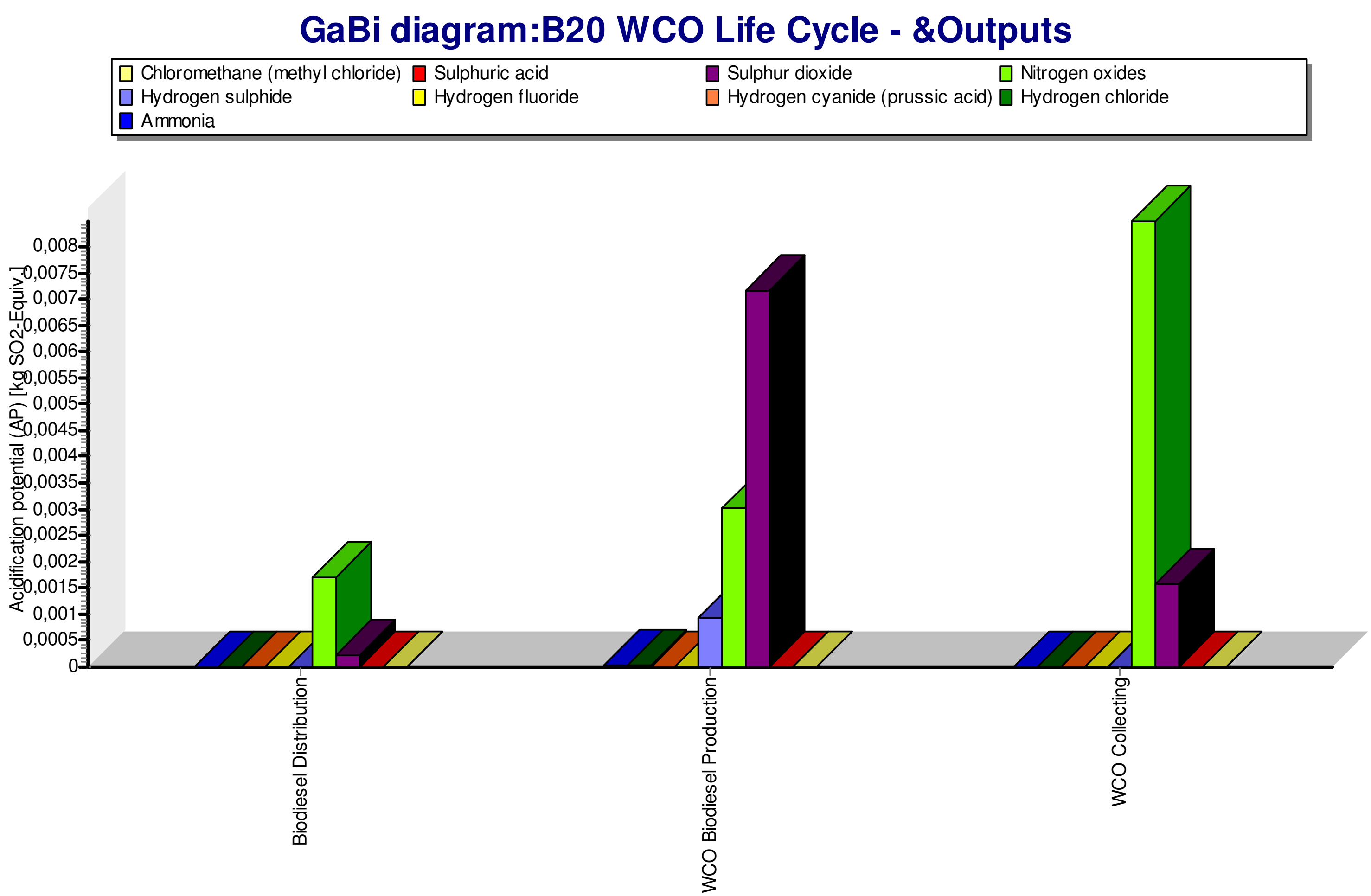

Figure D.31 : Detailed analysis of acidification potential for WCO biodiesel (B100) production for B20 WCO

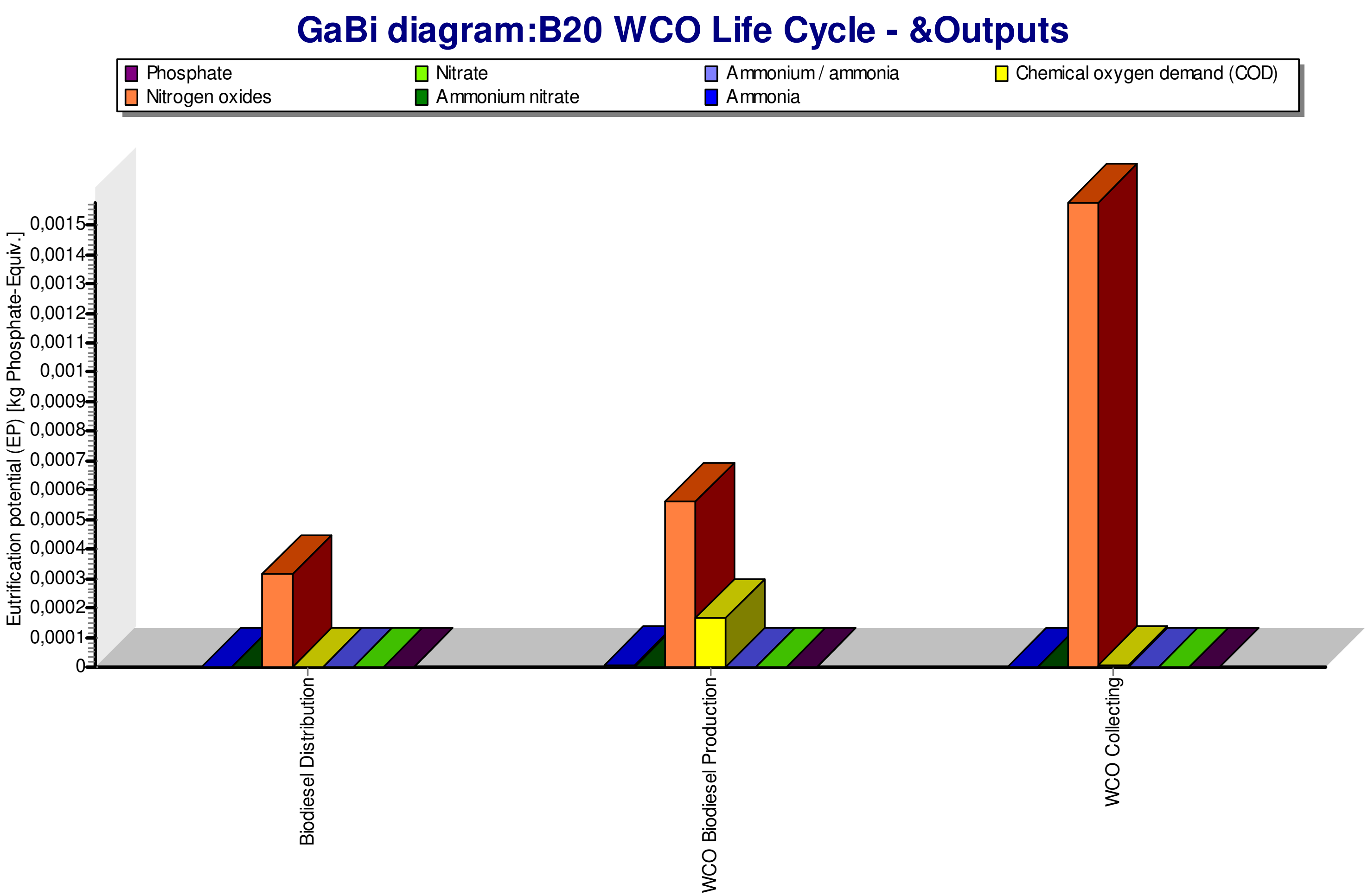

Figure D.32 : Detailed analysis of eutrophication potential for WCO biodiesel (B100) production for B20 WCO

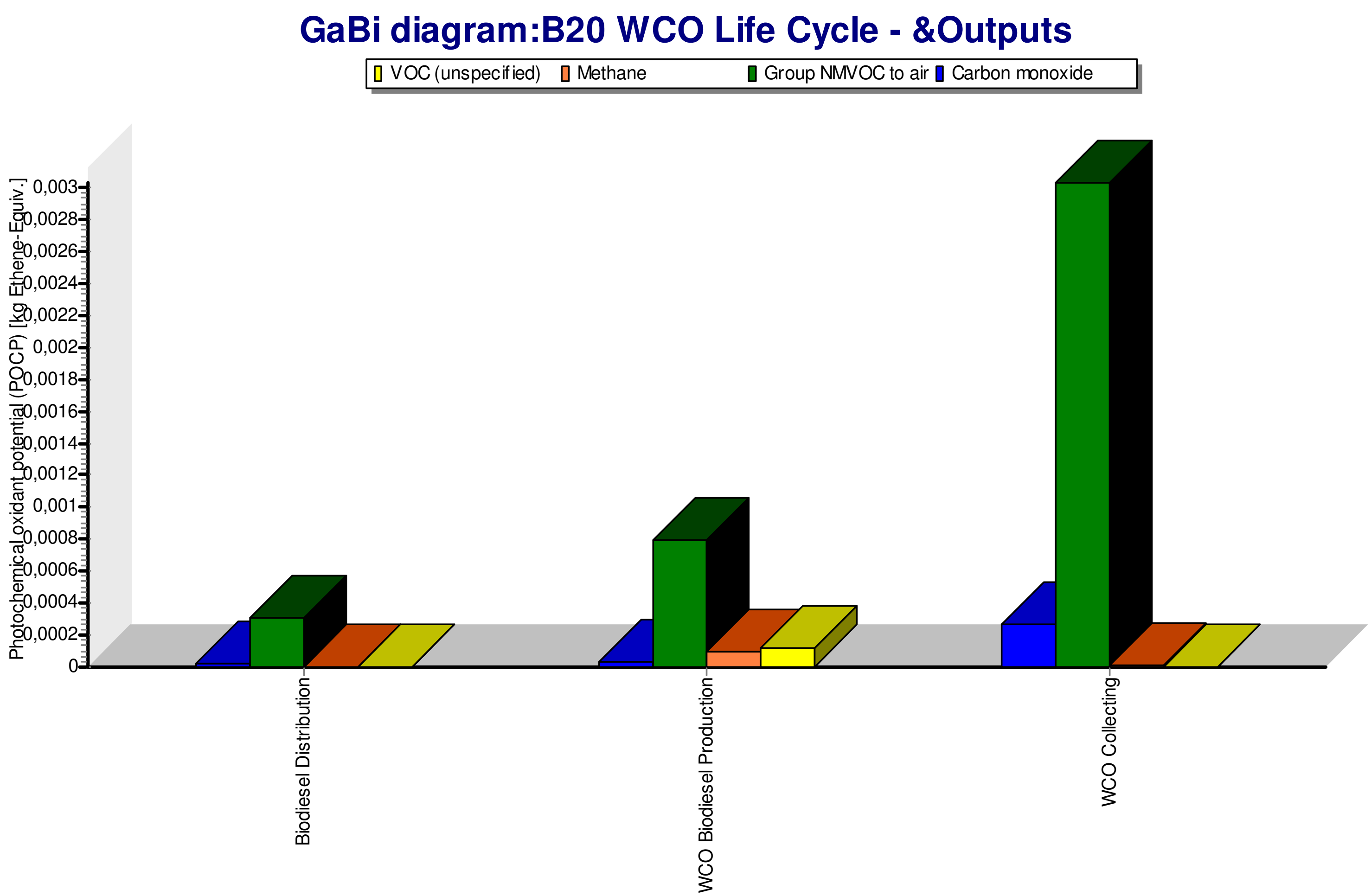

Figure D.33 : Detailed analysis of photochemical oxidant potential for WCO biodiesel (B100) biodiesel production for B20 WCO

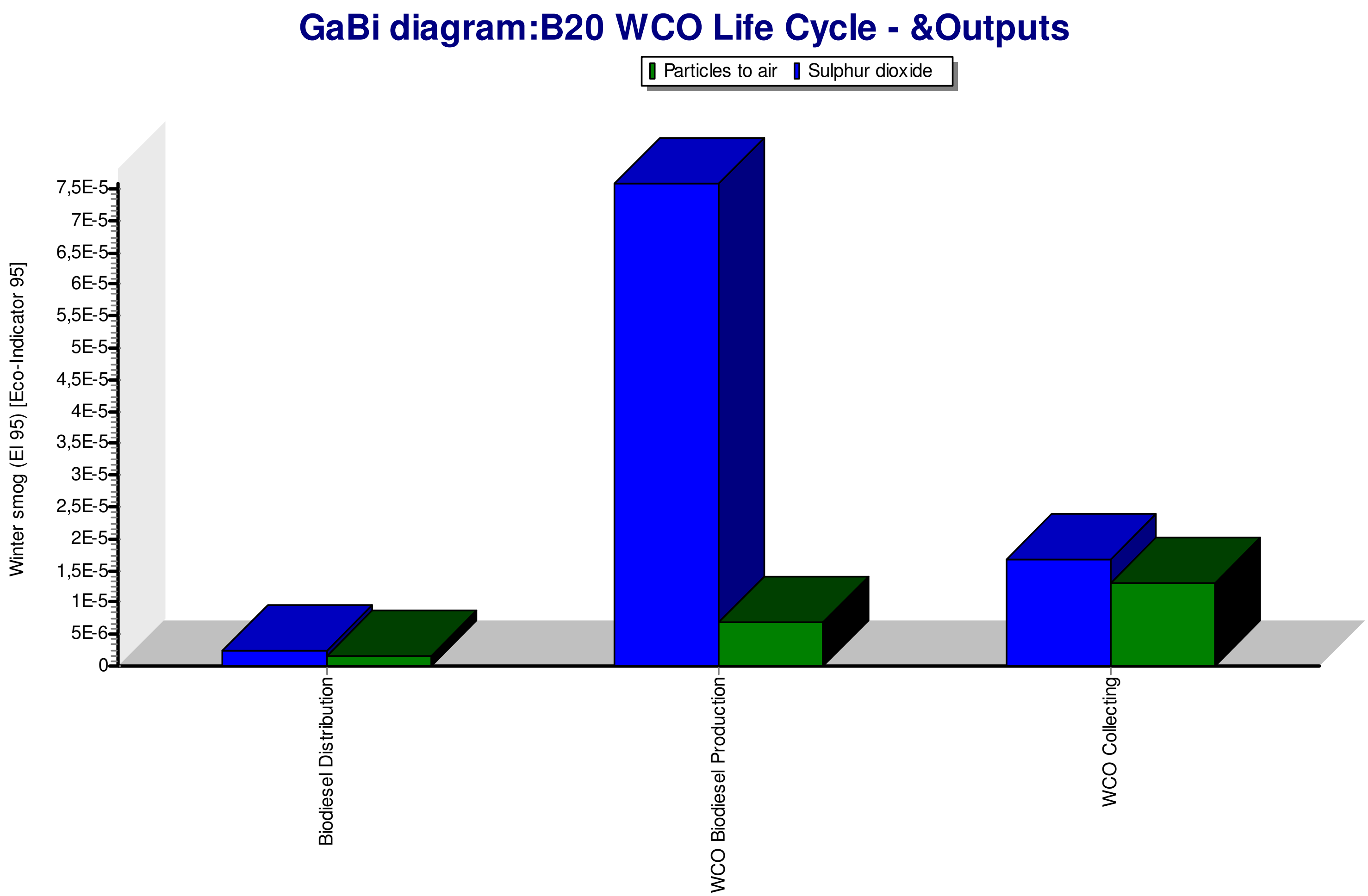

Figure D.34 : Detailed analysis of winter smog potential for WCO biodiesel (B100) production for B20 WCO

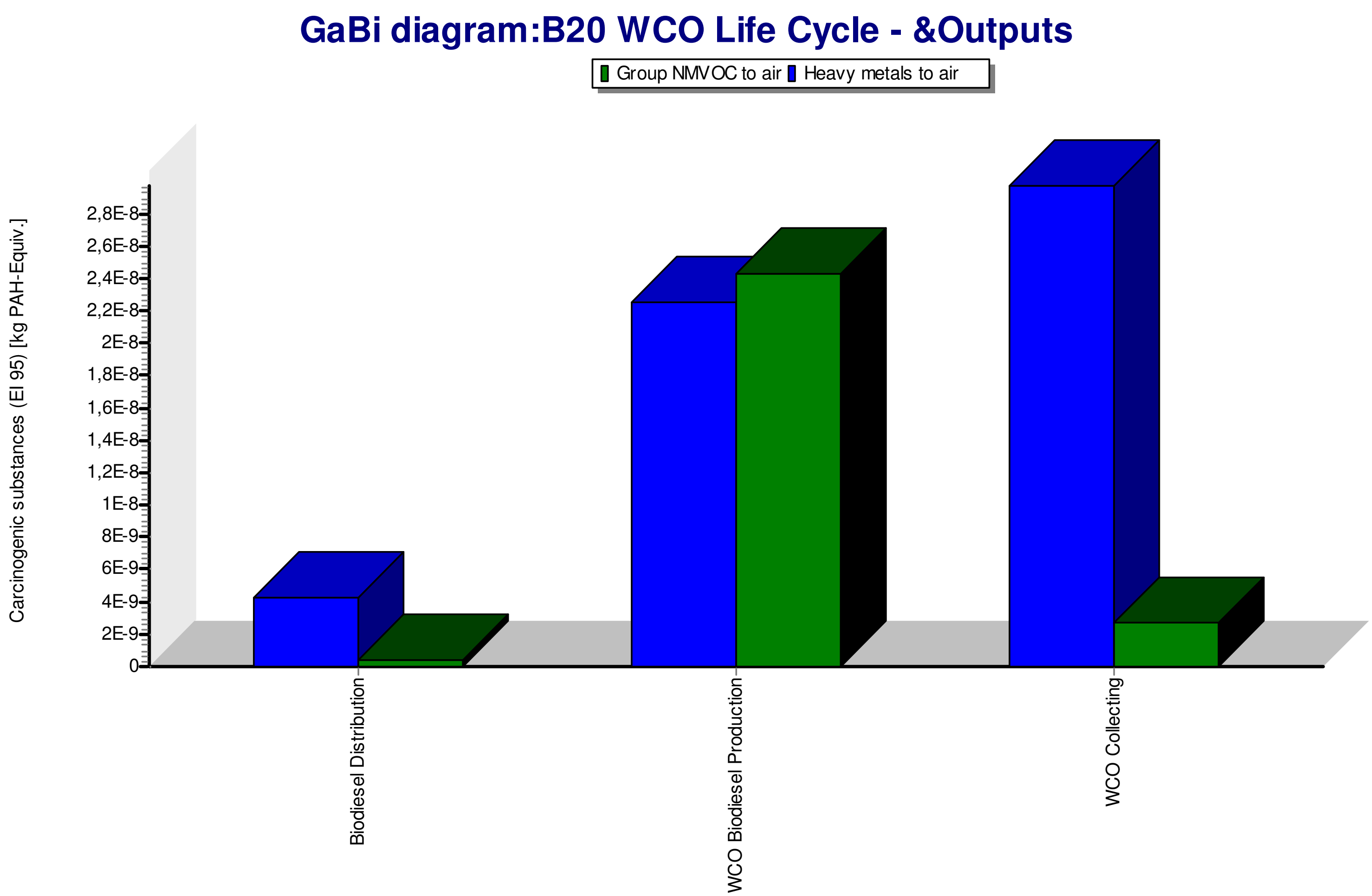

Figure D.35 : Detailed analysis of carcinogenic substances for WCO biodiesel (B100) production for B20 WCO

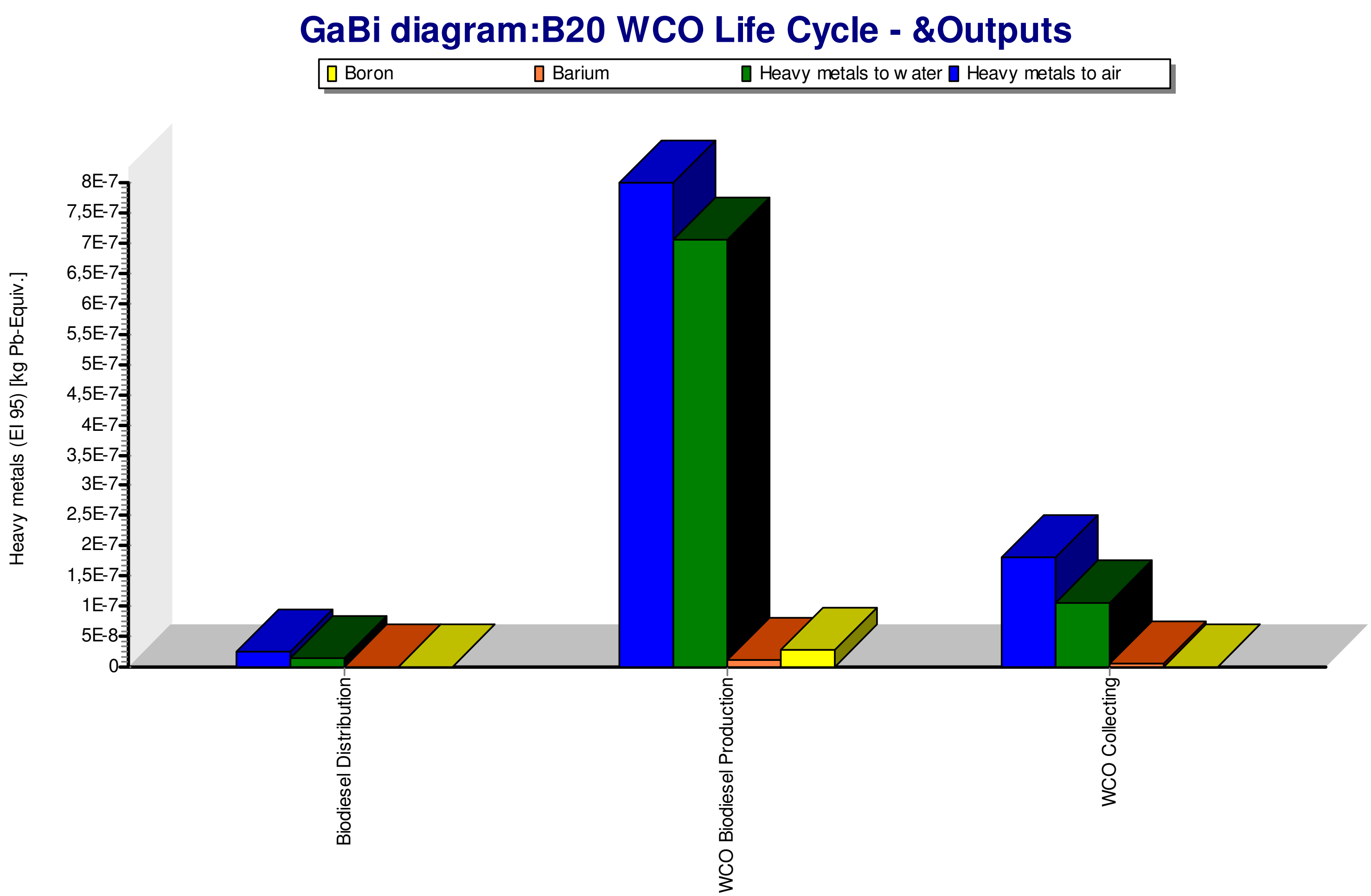

Figure D.36 : Detailed analysis of heavy metals for WCO biodiesel (B100) production for B20 WCO

Appendix E: Weighted Impact Potentials of the Fuels

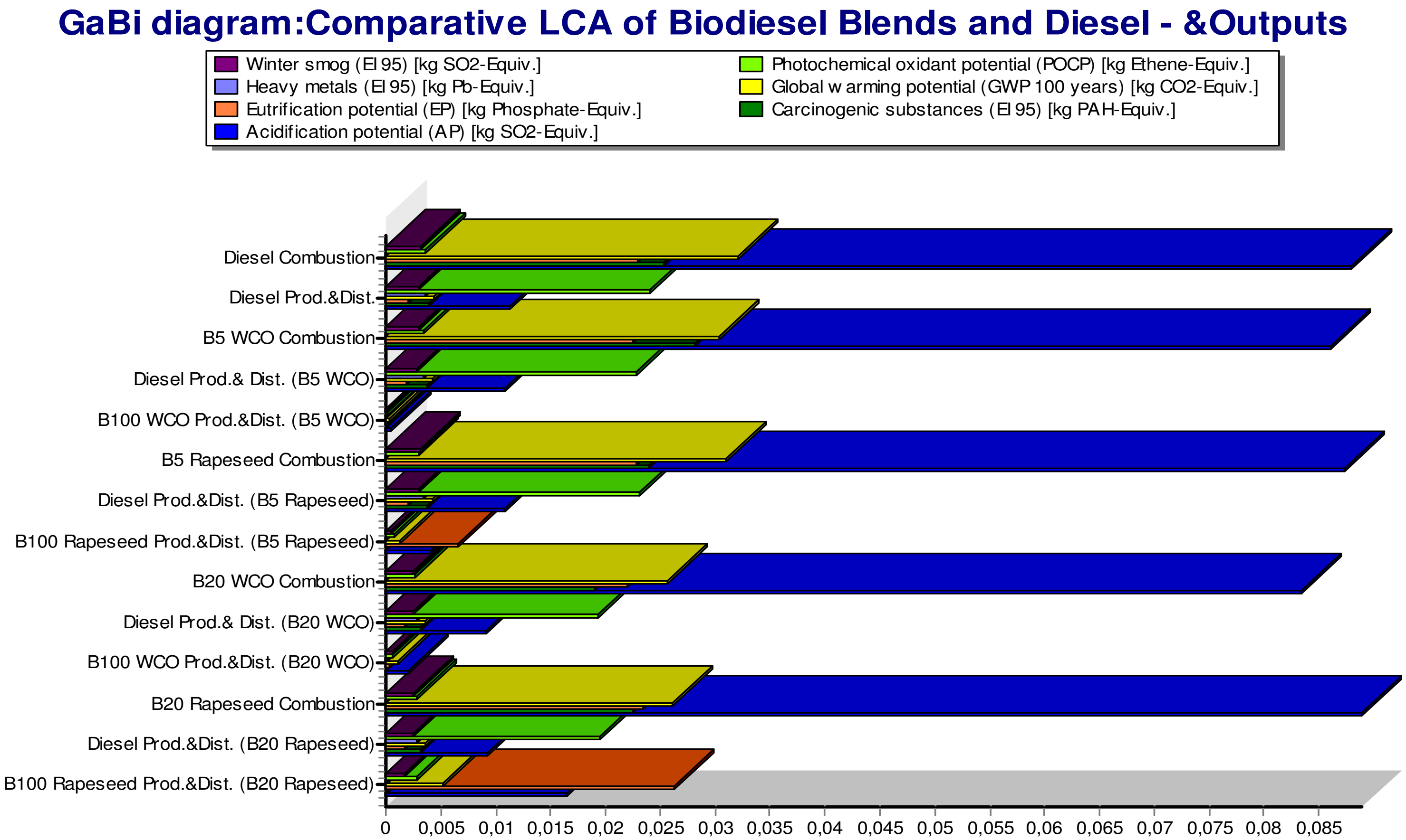

Figure E.1: Weighted impact potentials of fuels according to EcoIndicator95 (detailed graph)

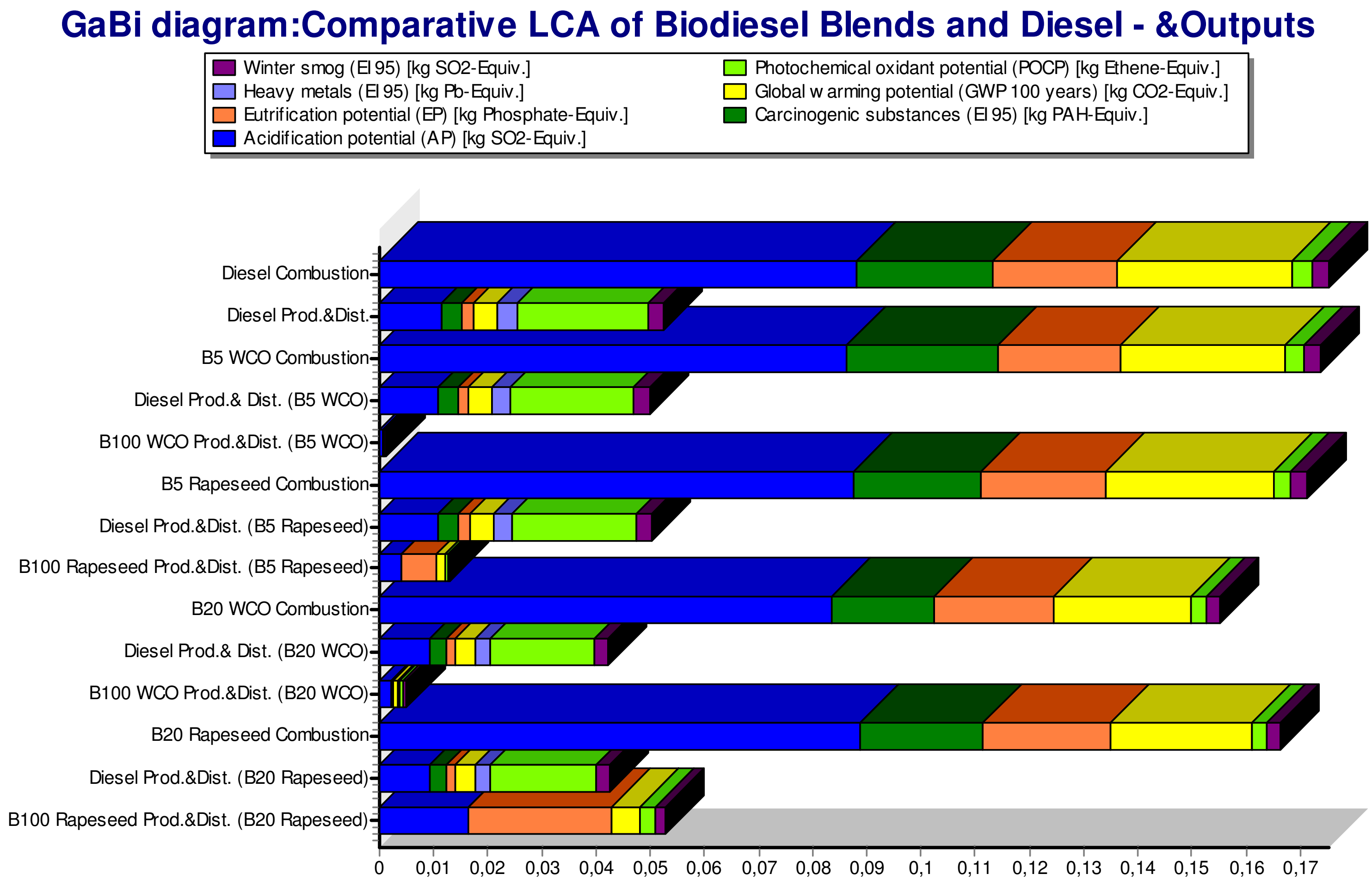

Figure E.2: Weighted impact potentials of fuels according to EcoIndicator95 (detailed graph, stacked)

Appendix F: Weighting results of the LCA of Fuels

Table F.1: Weighting results of the LCA of biodiesel blends and diesel.

	B20 Rapeseed	B20 WCO	B5 Rapeseed	B5 WCO	Diesel
Eco-Indicator 95 (Total Impact)	0,266981386	0,207642488	0,240767643	0,230672238	0,234195119
Acidification potential (AP) [kg SO2-Equiv.]	0,114609126	0,094632689	0,102402795	0,097449196	0,099427311
Carcinogenic substances (EI 95) [kg PAH-Equiv.]	0,025868914	0,022237316	0,027701211	0,031857517	0,029249520
Eutrophication potential (EP) [kg Phosphate-Equiv.]	0,051408527	0,023966875	0,031395257	0,024574606	0,025056955
Global warming potential (GWP) [kg CO2-Equiv.]	0,034870142	0,030295729	0,036514853	0,034921971	0,036635137
Heavy metals (EI 95) [kg Pb-Equiv.]	0,003096456	0,003059347	0,003487942	0,003443514	0,003589013
Photochemical oxidant potential (POCP) [kg Ethene-Equiv.]	0,025203495	0,022711709	0,026841308	0,026404209	0,027758107
Winter smog (EI 95) [kg SO2-Equiv.]	0,006750472	0,005627997	0,006416901	0,006090536	0,006245332

Table F.2: Weighting results of the LCA of B20 rapeseed.

	Biodiesel Distribution	Diesel Distribution	Biodiesel Production	Rapeseed Oil Transport	Rapeseed Production	Rapeseed Storage and Oil Extraction	Rapeseed Transport	B20 Rapeseed Combustion	Diesel refinery
Eco-Indicator 95 (Total Impact)	3,36E-04	1,27E-03	1,88E-03	2,22E-04	4,67E-02	3,25E-03	4,50E-04	1,66E-01	4,64E-02
Acidification potential (AP) [kg SO2-Equiv.]	1,72E-04	6,49E-04	7,45E-04	1,14E-04	1,48E-02	4,12E-04	2,31E-04	8,89E-02	8,58E-03
Carcinogenic substances (EI 95) [kg PAH-Equiv.]	4,37E-06	1,65E-05	2,46E-05	2,89E-06	4,50E-05	1,68E-05	5,85E-06	2,26E-02	3,19E-03
Eutrophication potential (EP) [kg Phosphate-Equiv.]	4,18E-05	1,57E-04	6,88E-05	2,76E-05	2,60E-02	5,66E-05	5,59E-05	2,35E-02	1,52E-03
Global warming potential (GWP) [kg CO2-Equiv.]	4,11E-05	1,55E-04	5,08E-04	2,71E-05	3,99E-03	5,17E-04	5,49E-05	2,61E-02	3,46E-03
Heavy metals (EI 95) [kg Pb-Equiv.]	3,97E-06	1,49E-05	7,78E-05	2,62E-06	4,58E-05	5,33E-05	5,31E-06	0,00E+00	2,89E-03
Photochemical oxidant potential (POCP) [kg Ethene-Equiv.]	4,61E-05	1,74E-04	1,20E-04	3,04E-05	5,71E-04	2,05E-03	6,17E-05	2,81E-03	1,93E-02
Winter smog (EI 95) [kg SO2-Equiv.]	1,98E-05	7,47E-05	3,07E-04	1,31E-05	1,20E-03	1,27E-04	2,65E-05	2,59E-03	2,39E-03

Table F.3: Weighting results of the LCA of B20 WCO.

	Biodiesel Distribution	Diesel Distribution	Biodiesel Production	WCO Collecting	B20 WCO Combustion	Diesel refinery
Eco-Indicator 95 (Total Impact)	3,31E-04	1,26E-03	2,61E-03	2,09E-03	1,55E-01	4,61E-02
Acidification potential (AP) [kg SO2-Equiv.]	1,70E-04	6,44E-04	9,91E-04	8,91E-04	8,34E-02	8,51E-03
Carcinogenic substances (EI 95) [kg PAH-Equiv.]	4,31E-06	1,63E-05	4,30E-05	2,97E-05	1,90E-02	3,16E-03
Eutrophication potential (EP) [kg Phosphate-Equiv.]	4,12E-05	1,56E-04	9,65E-05	2,07E-04	2,20E-02	1,51E-03
Global warming potential (GWP) [kg CO2-Equiv.]	4,04E-05	1,53E-04	7,31E-04	2,77E-04	2,57E-02	3,44E-03
Heavy metals (EI 95) [kg Pb-Equiv.]	3,91E-06	1,48E-05	1,42E-04	2,70E-05	0,00E+00	2,87E-03
Photochemical oxidant potential (POCP) [kg Ethene-Equiv.]	4,54E-05	1,72E-04	1,45E-04	4,61E-04	2,69E-03	1,92E-02
Winter smog (EI 95) [kg SO2-Equiv.]	1,95E-05	7,41E-05	4,13E-04	1,48E-04	2,60E-03	2,38E-03

Table F.4: Weighting results of the LCA of diesel.

	Diesel Distribution	Diesel refinery	Diesel Combustion
Eco-Indicator 95 (Total Impact)	1,56E-03	5,73E-02	1,75E-01
Acidification potential (AP) [kg SO2-Equiv.]	8,01E-04	1,06E-02	8,80E-02
Carcinogenic substances (EI 95) [kg PAH-Equiv.]	2,03E-05	3,93E-03	2,53E-02
Eutrophication potential (EP) [kg Phosphate-Equiv.]	1,94E-04	1,87E-03	2,30E-02
Global warming potential (GWP) [kg CO2-Equiv.]	1,91E-04	4,28E-03	3,22E-02
Heavy metals (EI 95) [kg Pb-Equiv.]	1,84E-05	3,57E-03	0,00E+00
Photochemical oxidant potential (POCP) [kg Ethene-Equiv.]	2,14E-04	2,39E-02	3,67E-03
Winter smog (EI 95) [kg SO2-Equiv.]	9,22E-05	2,96E-03	3,20E-03

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